Mighty Macrophages • Plasmas • Solidifying Molten Metals • Tree Lignin

Space Research

Office of Biological and Physical Research

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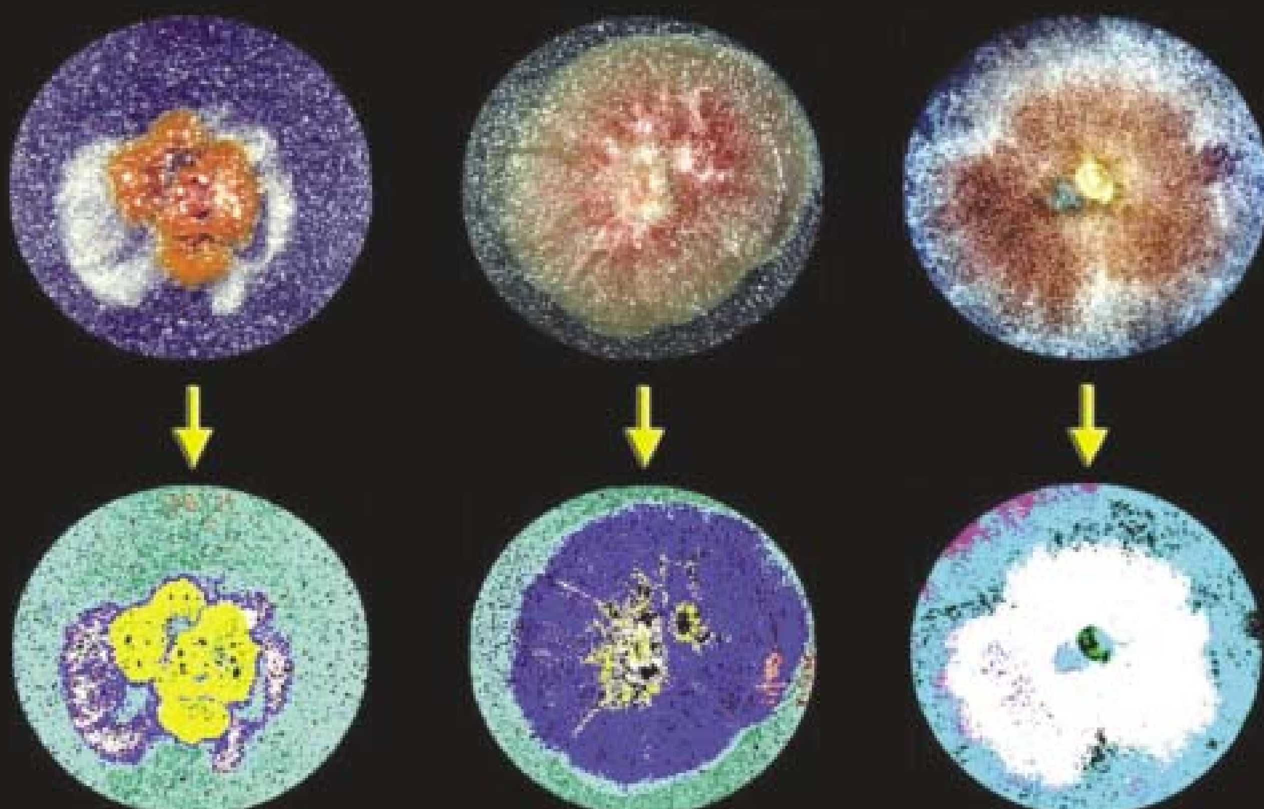
Securing the Home Planet



Profile:
Khalid Alshibli

National Aeronautics and Space Administration

Letter From the Associate Administrator

At first glance, an office building and the International Space Station (ISS) may seem to have little in common. But the same concerns for safety and health that keep a crew fit for extended periods in space may also help maintain a safe indoor environment for people on Earth from day to day — or possibly in the event of a biological terrorism threat.

The ISS is a system with carefully monitored air that astronauts breathe, water they drink, and food they eat. Contaminants in a space system could pose a significant threat to the crew on board. Similarly, many buildings today have windows that are sealed, with the ventilation and other life-support elements of the working environment regulated from within.

In "Protecting the Home Planet," you will read about how research sponsored by the Office of Biological and Physical Research is helping us learn how to ensure an even safer environment for our astronauts working on the ISS. You will also read about how that same research might be applied to improved, safer living and working environments here on Earth. For example, technology developed to rid enclosed plant growth chambers of the natural but harmful byproduct ethylene can be applied on Earth not only to keep produce fresher longer but also to thwart many types of spores, bacteria, and viruses that could be introduced into building ventilation systems. Water supply tests developed for the ISS also can be adapted to test public water supplies for specific strains of bacteria or toxins. Technology developed for remote sensing satellites could be adapted for detecting such food contaminants as the presence of harmful molds in a shipment of grain or bacteria on a raw chicken carcass.

In fact, NASA has more than 275 research projects that not only contribute toward a safe working environment for ISS crew members but also toward some aspect of homeland security. Some of these dual-use projects are funded by OBPR — not surprising since we and our predecessors have long supported research valuable to the safety of astronauts' air, water, and food.

As we become residents of, not visitors to space, evolving technology that keeps astronaut crews healthy in space also helps those charged with protecting life on Earth. Because this research can be so valuable to efforts for protecting the United States and the rest of the world, too, we join other federal agencies in sharing information with the Department of Homeland Security. Through Amy Donahue, NASA's senior adviser to the Administrator for homeland security, we keep other agencies aware of developments in our research that can help keep this planet a safe place to live.

Mary E. Kicza

Mary Kicza
Associate Administrator
Office of Biological and Physical Research

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On the cover:
A hyperspectral sensor system based on NASA remote-sensing technology allows harmful molds to be differentiated quickly from harmless ones using differences in their spectral signatures (patterns of color). Here the physical appearances of three molds in petri dishes (top) are shown with their corresponding hyperspectral images (bottom). credit: NASA

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Botanist Terri Lomax Selected to Lead Fundamental Space Biology Division

credit: NASA

Terri Lomax, a botany and plant pathology professor at the Cascades campus of Oregon State University (OSU) in Bend, is becoming the new director of the Office of Biological and Physical Research's Fundamental Space Biology Division. Lomax, who was selected in March by NASA Associate Administrator Mary Kicza, will lead the division's $150 million annual research program. The long-time NASA researcher at OSU brings to the position a valuable combination of nationally and internationally renowned scientific expertise plus a commitment to educational outreach and public outreach.

Lomax first became involved with NASA in 1995 when her research to find out how plants 'know' where gravity is received NASA funding. Lomax's experiment — how multiple hormones interact to regulate plant growth and responses to the environment, including gravity — was conducted aboard the Space Shuttle *Discovery* in 1998. Her research group also is investigating the mechanism of action of the plant-growth hormone auxin and is developing a genomics-based system for assessing and controlling plant growth in space environments.

In addition to dividing her time between plant research and teaching at OSU, Lomax has also been active in educational outreach and public outreach activities. In 1998, she founded Science Connections, a university science educational outreach program for students in kindergarten through the 12th grade. In 2000, she founded OSU's Program for the Analysis of Biotechnology Issues, which provides information about genetically engineered crops to the public, press, and policy makers.

Lomax received a bachelor's degree in botany from the University of Washington in Seattle in 1975, a master's in botany and biology from San Diego State University, California, in 1978, and a doctorate in biological sciences from Stanford University, California, in 1983. She was a Fulbright Fellow at the University of Freiburg, Germany, an Aldo Leopold Leadership Program Fellow, and is currently a Fellow of the NASA Institute for Advanced Concepts, an institute of the Universities Space Research Association (USRA). USRA is a private nonprofit corporation under the auspices of the National Academy of Sciences that fosters cooperation among universities, other research institutions, the U.S. government, and other organizations to develop knowledge of space science and technology.

Shannon Lucid Chosen as NASA's New Chief Scientist

credit: NASA

Astronaut Shannon Lucid, the only woman to be awarded the Congressional Space Medal of Honor by the President of the United States, has been chosen by NASA Administrator Sean O'Keefe as NASA's new chief scientist. Lucid, who holds the U.S. record for single-mission flight endurance (188 days) aboard Russian Space Station *Mir*, will be responsible for ensuring the scientific merit of NASA's programs. She plans to make sure that science remains a central focus of all of NASA's exploration activities.

Before being chosen as chief scientist, Lucid supported space shuttle and International Space Station missions as a spacecraft communicator. A biochemist and educator, Lucid was among the first six women selected for the astronaut corps in 1978, and she became an astronaut in 1979. The first of her five space shuttle missions was on STS-51G in 1985. In 1996 she flew on STS-76 to *Mir*, where she remained for six months, returning to Earth on STS-79. During her time aboard *Mir*, Lucid conducted numerous life and physical sciences experiments and traveled more than 75 million miles. Russian President Boris Yeltsin honored her with the Order of Friendship Medal, one of the highest Russian civilian awards and the highest that can be awarded to a noncitizen.

Lucid received a bachelor's degree in chemistry from the University of Oklahoma in 1963, followed by a master's and doctorate in biochemistry in 1970 and 1973, respectively. She replaces former chief scientist Kathie Olsen, who now seves as associate director for science in the Office of Science and Technology Policy in the Executive Office of the President [of the United States].

Fluent Russian Speaker Serves as Expedition 7 ISS Science Officer

credit: NASA

The first American to serve as second in command of a Russian *Soyuz* spacecraft is working as the Expedition 7 science officer for the International Space Station (ISS). Edward Lu, a Russian-speaking physicist who specializes in solar and astrophysics, is overseeing the life and physical sciences research currently being conducted on the ISS.

Lu and Expedition 7 commander Yuri Malenchenko flew to the ISS on April 28 aboard a Soyuz spacecraft instead of a space shuttle because the space shuttle fleet has been grounded during the *Columbia* accident investigation. Lu was able to prepare for his flight on the Soyuz in just nine weeks, a feat made possible by his fluency in Russian. Lu and Malenchenko are the only Expedition 7 crew members because crew size is now limited to two to minimize the requirements for resupplying water, food, and other necessities while the space shuttle fleet is grounded.

Lu received his bachelor's degree in electrical engineering from Cornell University, Ithaca, New York, in 1984, and his doctorate in applied physics from Stanford University, Stanford, California, in 1989. He worked in solar physics and astrophysics as a visiting scientist at the High Altitude Observatory in Boulder, Colorado, until 1992, when he became a postdoctoral fellow at the Institute for Astronomy in Honolulu, Hawaii, where he remained until 1995. Lu has developed theoretical advances that have provided a fundamental understanding of the physics of solar flares.

In December 1994, NASA selected Lu for the astronaut corps, and he reported for training to Johnson Space Center in March 1995. At NASA Lu has worked in the astronaut office computer support branch and as the lead astronaut for ISS training issues.

Lu and Malenchenko will remain aboard the ISS until October. The two astronauts served in space together previously when they flew to the ISS aboard the space shuttle *Atlantis* (STS-106) in September 2000 to ready the station for its first permanent crew. Lu also flew aboard *Atlantis* in 1997 (STS-84) on a mission to exchange American crewmembers in the Russian Space Station *Mir*.

Online Service Offers OBPR News Updates

There is good news for people who want to keep abreast of the latest information from the Office of Biological and Physical Research (OBPR): news updates are now available from OBPR's free online news service. Every week or two, OBPR will send subscribers an e-mail message with half a dozen headlines and links to the full stories on the OBPR Web site. Articles include updates on scientific research, education information, notices of upcoming meetings, and other OBPR announcements.

Anyone wishing to subscribe should go to *http://spaceresearch.nasa.gov*, click on "Join the OBPR Mailing List" link in the lower left corner of the page, and send a blank e-mail message. The new subscriber will then receive a confirmation welcome message, followed by regular news and announcements about OBPR activities.

Survey

You're the expert on what you want in a NASA OBPR magazine. So, the staff and editorial review board of *Space Research* want to find out from you whether we're delivering a quarterly that works.

Please take five minutes to answer a few multiple-choice questions on our web site at *http://spaceresearch.nasa.gov/survey.html*. In early October, we'll compile your answers and then share the results and the changes you have suggested in the next issue of *Space Research*.

We look forward to hearing from you!

Securing the Home Planet

Technologies developed by NASA's Office of Biological and Physical Research to keep air, water, and food safe for astronauts in space can also help protect people on Earth from bioterrorism.

credit: Wisconsin Center for Space Automation and Robotics, University of Wisconsin

This miniature closed-system greenhouse used for growing green plants in microgravity, designed by Principal Investigator Weijia Zhou and his colleagues at the Wisconsin Center for Space Automation and Robotics, is equipped with a "scrubber" to remove ethylene (a natural gas byproduct emitted by plants) from the chamber's atmosphere. (Seedlings inside the chamber are bathed in the pink glow of grow lights; the two large white circles are openings to gloves that allow astronauts access to the plants.)

For decades, one of NASA's missions has been to keep astronauts healthy in space, where there are no alternate sources for air, water, or food should a craft's supply become contaminated. Control over an enclosed environment takes on increasing importance as humans prepare to explore beyond low Earth orbit, moving farther away from potential sources of aid on Earth.

Moreover, NASA now shares a responsibility (along with other federal agencies) to contribute to this nation's homeland security as part of its greater mission to understand and protect the planet. In a troubled world that now includes threats of biohazards and bioterror, NASA's long experience in monitoring air, water, and food also may play a significant role in helping to protect the home planet, whether from natural diseases or the deliberate acts of individuals or groups.

In September and October 2001, several U.S. post offices and two U.S. Senate buildings were shut down when anonymous envelopes containing mysterious powders were found to contain spores of the bacterium *Bacillus anthracis*, which cause the disease anthrax. Since then, public officials and others have openly discussed the potential threat of future acts of bioterrorism: the unleashing of "weaponized" biological agents such as *Bacillus anthracis*, the smallpox virus, or *Clostridium botulinum* (which produces the botulinum toxin that causes botulism poisoning).

In August 2002, NASA Administrator Sean O'Keefe appointed a senior adviser for homeland security, Amy Donahue, as a liaison to the Office — now the Department — of Homeland Security (see sidebar on page 24, NASA's Liaisons for Homeland Security). Donahue capitalized upon efforts at NASA Headquarters and NASA centers to identify technologies valuable not only to NASA's space mission but also possibly to homeland security. By early 2003, NASA's list of potential dual-use technologies had topped 275 research projects and was still growing.

Many of NASA's dual-use projects fall under the purview of the Office of Biological and Physical Research (OBPR), which has long funded research into ensuring the safety of air, water, and food for astronauts, especially for long-duration missions.

Two Purposes, One Challenge

The technical challenges of devising early-warning systems for compromised air, water, and food in space and on Earth are surprisingly similar, according to Jitendra Joshi, deputy program manager for advanced human support technology at NASA Headquarters. And those challenges are tough ones.

For long-duration missions during which astronauts would need to recycle air and water and perhaps grow their own food, a principal concern is a slow buildup of trace toxic elements or microorganisms. Monitoring a slow buildup requires extraordinarily sensitive instruments operating continually, explains Darrell Jan, manager of NASA's Advanced Environmental Monitoring and Control Program Element. "On the other hand, any leak of hazardous gases can spread very rapidly, so we need quick detection. And the instruments must give reliable results."

As with any other payload on spacecraft, Joshi adds, "instruments also need to be compact (low-mass and low-volume), autonomous (low-maintenance), and low-power. They must also consume few expendable supplies and generate little waste. Lastly, they must require little expertise to operate, so astronauts can devote most of their time to tasks other than tending life-support systems."

Back on Earth, what instruments are needed for regular testing of air coming into buildings, drinking water flowing into treatment plants from reservoirs, and food prepared in a processing plant or restaurant? They, too, need to operate continually and be sensitive, fast, and autonomous. Moreover, police, fire, and health-care workers responding to an emergency would also need instruments that are compact, NASA now shares a responsibility (along with other federal agencies) to contribute to this nation's homeland security as part of its greater mission to understand and protect our home planet.

low-power, reliable, durable, and straightforward to operate, which also use few consumables and produce little waste.

Protecting Air

Modern energy-conserving office buildings are essentially closed systems. Windows are hermetically sealed and more than 80 percent of the air inside the buildings is recycled; thus, some large buildings draw in scarcely a fifth of their volume of fresh air from the outside daily. Although recycling air minimizes heating and cooling costs, it also increases the potential that contaminants (such as outgassing from insulation or car exhaust from an underground garage) might accumulate in the indoor air.

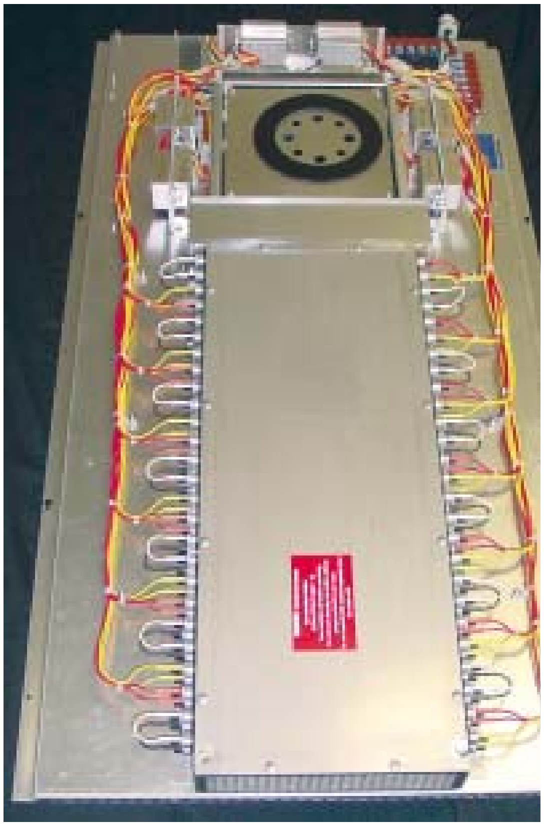
But what if there is a conscious, calculated plan to inflict suffering and fear by intentionally introducing an airborne biological agent such as anthrax spores or a chemical toxin such as nerve gas? An energy-efficient building's air recirculation system will tend to transport the agent — which may well be colorless and odorless — throughout the entire building, actually impeding its removal and posing a serious threat to everyone within. What technology could destroy such airborne agents?

One possibility is a compact machine based on an ethylene scrubber originally devised by Weijia Zhou, director of the Wisconsin Center for Space Automation and Robotics (WCSAR) at the University of Wisconsin, Madison. Zhou and his colleagues developed a machine to eliminate contaminant hydrocarbons — primarily ethylene — normally produced by growing plants, which can pose problems in an enclosed environment. Growing green plants in microgravity as possible vegetable crops for astronauts on long-duration missions is significant to NASA.

Although the Russians in Space Station *Mir* allowed their experimental green plants to share the cabin air with cosmonauts, Zhou explains, since the 1980s NASA has emphasized that plant research and experiments conducted aboard the space shuttle or the International Space Station (ISS) should be enclosed in chambers. Air must not be exchanged between plant chambers and the orbiter cabin without sufficient filtration. As a result, each growth chamber has its own subsystems for controlling nutrient delivery, lighting, humidity, temperature, and atmospheric composition, with stringent limits on consumable supplies and the disposal of waste heat, moisture, and gases — a tall order for months-long missions on the ISS.

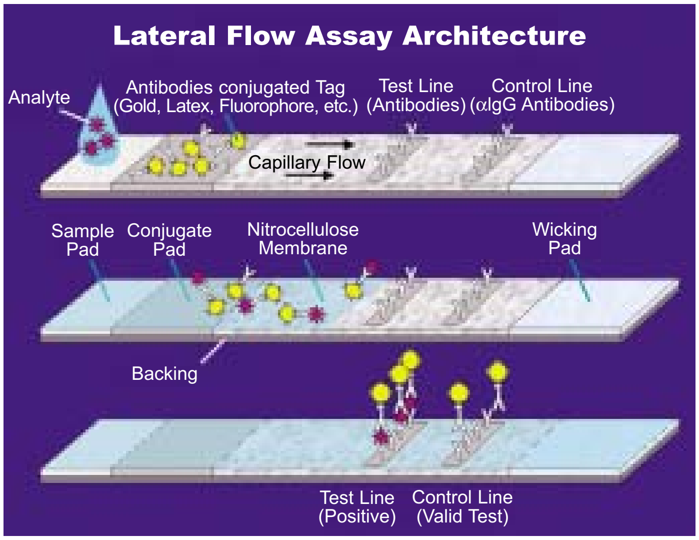
Now, plant physiologists have long known that growing plants produce ethylene, an odorless gas that, to plants, acts as a hormone, causing them to mature early and go to seed (ethylene gas is what ripens bananas in a few hours if they are kept enclosed in a paper bag). Indeed, plants are so sensitive to ethylene that concentrations as low as 50 parts per *billion* (ppb) may affect plant reproduction (seed development), Zhou says, and concentrations of 200 ppb may interfere with the pollen process and even abort the formation of seeds. On Earth, the ethylene diffuses into the atmosphere and is dispersed. But in an enclosed growth chamber, its concentration could build up to lethal levels for the plants within days.

To safeguard the plants on space shuttle flights of only a week or two, filter paper impregnated with chemicals that absorb ethylene does the trick. "But chemical absorbents are consumables that must be replenished. So [for ISS missions] our folks had to develop non-consumable degradation technology," recalls Zhou. The heart of their ethylene scrubber is the white pigment titanium dioxide (TiO_2), which is not consumed because it is a photocatalyst. "Under ultraviolet irradiation, the scrubber fully oxidizes ethylene and other hydrocarbons into carbon dioxide (CO_2) and water vapor (H_2O). Thus, not only did we get rid of the ethylene, we also broke it down into byproducts not harmful to plant growth — which is why this technique is pretty good!" Zhou exclaims.



credit: KES Science and Technology Inc.

The ethylene-scrubber technology led to the development of an air filtration device, the AiroCide TiO_2, which can kill dangerous microbes, including spores of the bacterium that causes anthrax. A fan (black circle at the far end) draws in the room air and forces it through a maze of tubes, where chemically reactive hydroxyl radicals and high-energy ultraviolet light attack and kill pathogens.



credit: NASA

The Quantitative Lateral Flow Assay (QLFA) is a "test strip" for identifying biological organisms in an analyte (liquid sample), which flows from the sample pad to the wicking pad. On the conjugate pad, specific antibodies (Y shapes) tagged with chemical markers (yellow ovals) bind to the target antigen (red sunbursts) in the sample and flow toward the wicking pad. At the test line, other immobilized antibodies bind the antigens to produce a positive test result, revealed as fluorescing color. A control line antibody confirms the test ran successfully; that is, the sample flowed the length of the test strip.

Over the past decade, WCSAR plant growth chambers equipped with photocatalytic ethylene scrubbers have flown on nine space shuttle flights, three ISS missions, and even once on *Mir*.

In 1998, Zhou's ethylene scrubber caught the attention of John Hayman Jr., chairman of KES Science and Technology Inc. in Kennesaw, Georgia. Two decades ago, Hayman invented the produce-misting systems widely used in grocery stores. Now Hayman has licensed WCSAR's technology to develop a commercial ethylene scrubber for florists and grocers seeking to lengthen the shelf life of flowers, fruits, and vegetables kept in cold storage (any refrigerator is also an enclosed system). He added some fans to circulate air through the unit and some germicidal lights inside the unit to kill airborne bacteria and molds, called his development the Bio-KES, and began marketing it to the perishable foods and floral industries.

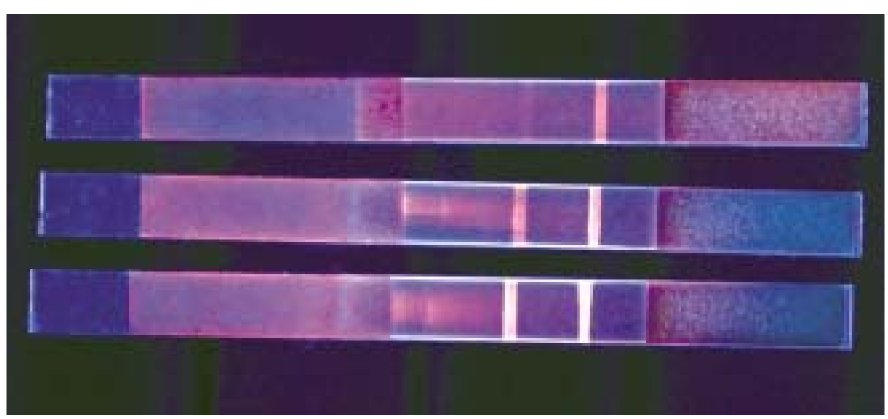
But shortly after the first anthrax attacks in late 2001, Hayman recalls, "We were having a managers' meeting, and one manager asked, 'Gee, boss, do you think the Bio-KES could kill anthrax spores?'" When a first test of an unmodified Bio-KES killed 83 percent of *Bacillus thuringiensis* (a harmless bacillus bacterium with spores that are similar to *Bacillus anthracis* and widely accepted in the scientific world as a sufficient substitute), ramping up further development "was a no-brainer," Hayman says. After replacing the Bio-KES's germicidal bulbs with 52 ultraviolet lamps so that spores and other airborne pathogens would be bombarded by high-energy UV photons as air is drawn through the unit, the kill rate was raised to 99.99998 percent of spores. "Killing spores, with their basketball-like hard shells, is 50 times harder than killing any vegetative [live] bacteria, such as those that cause tuberculosis or staph infections, or even viruses — so the process also should be effective against smallpox," Hayman points out.

By March 2002, NASA and Hayman jointly announced the modified Bio-KES under the name AiroCide TiO_2 as a solution for antiterrorism and emergency preparedness. In January 2003 it gained clearance from the Food and Drug Administration as a class II medical device (a device allowed to be used in hospitals), and it is now undergoing pilot tests. Hayman envisions that the AiroCide should find uses in hospitals, schools, and daycare centers as well as in police headquarters, mobile military vehicles, and emergency response team headquarters.

Monitoring Water

For the purposes of bioterrorism, a major city's water supply could be a prime target. Contaminating a few central reservoirs could have a dramatic effect in terrifying the local population, even though most microbes and toxins would be neutralized at the water treatment plant before being pumped to homes and offices. But contaminating the supply *after* it leaves the water treatment plant for individual neighborhoods could have grave consequences.

The technology currently used aboard the ISS for detecting the presence of pathogens in the astronauts' recycled drinking water is "frankly, pretty archaic," remarks James Lambert, supervisor of the Intelligent Instruments group at the Jet Propulsion Laboratory (JPL) in Pasadena, California. NASA specifies that on the space shuttle, astronauts' drinking water must contain no more than 100 colony-forming units (CFUs) — that is, no more than 100 live bacteria of any kind capable of forming a colony — per 100 milliliters (about a third of a cup). Although this is actually less rigorous than the Environmental Protection Agency's standard for drinking water on Earth, NASA finds it acceptable, as long as the water is tested regularly — maybe once a day. Astronauts test their drinking water by drawing 100-milliliter samples through a filter impregnated with a growth medium to trap any



As easy to read as a home pregnancy test, three QLFA strips used to test water for *E. coli* show different results. The brightly glowing control line on the far right of each strip indicates that all three tests ran successfully. But the glowing test line on the left in the middle and bottom strips reveal their samples were contaminated with *E. coli* bacteria at two different concentrations (the color intensity of the lines correlates with concentration).

credit: NASA

credit: Microanalytical Instrumentation Center, Iowa State University

The heart of a colorimetric solid-phase extractor (CSPE) test kit quickly measures the concentration of the biocides silver or iodine in astronauts' drinking water to determine whether concentrations are safe. When 10 ml of water is drawn through the disk, the disk will turn color (yellow in the photo) indicating the presence of the biocide. The device could some day be used to test water safety at reservoirs and water treatment plants on Earth.

bacteria, and culturing the bacteria (allowing them to multiply so they are detectable) for five days. The colonies are grown with an indicator that causes them to show up on the filter as purple spots, whose number is estimated by comparison to a chart.

With a five-day culture necessary to detect the bacteria, however, "it may be a horserace between whether the astronauts turn green or the filter turns purple first," Lambert observes wryly. "What you really want is a test that detects what is there in five *minutes*."

Lambert's team has recently developed a prototype of a one-step test strip that he has designed to be as simple to use as an over-the-counter pregnancy test kit. "With a pregnancy test, you dip a chemically-treated stick into a urine sample and wait for five minutes to see if it turns blue," Lambert explains. "It is a simple yes-no test: if it turns color, you are pregnant; if it does not, you are not."

Technically known as a quantitative lateral flow assay (QLFA), Lambert's test strip consists of an absorbent membrane on a stiff backing. When a water sample is applied to one end of the strip, the water diffuses along the length of the strip, passing several stripes (narrow regions) impregnated with high concentrations of specific antibodies. Each of the stripes is chemically treated with different compounds so that they will turn color in the presence of specific antigens. When bacteria with the target antigen flow into the stripe, they are bound by the antibodies, causing the stripe to change color, revealing their presence. Depending on the QLFA's design and the specific antibodies used, in minutes the test strip yields not only a rough count of the total CFUs in the water sample, but also a preliminary classification as to the types of organisms present — for example, viruses versus different major classes of bacteria (there are no universal antibodies that can detect every type of organism). "Similar strip tests can be developed for testing water in public water supplies for specific strains of bacteria or toxins," Lambert declares.

Meanwhile, keeping the bacteria count low in drinking water is a concern for Marc Porter, Jim Fritz, and their research team (Bob Lipert, Dan Gazda, and Lisa Ponton) at Iowa State Univeristy's Microanalytical Instrumentation Center (MIC), in Ames, Iowa. In the space shuttle or the ISS, that task is surprisingly tricky. "It is not possible to sterilize water enough to store it for extended periods without having bacteria grow," Porter explains. "You really need to add a biocide" — that is, a chemical to kill bacteria. Although chlorine is commonly used on Earth, NASA uses molecular iodine while the Russians use silver ions.

The concentration of the biocide itself needs to be closely monitored, however, not only to keep it above a minimum effective level for killing bacteria, but also to keep it *below* a level harmful to the astronauts. For example, Porter says, too much iodine has been linked to thyroid problems; too much silver, on the other hand, "irreversibly turns your skin blue," an unusual condition called argyria.

To monitor biocide levels, the MIC team has developed and flight-tested a chemical sensor system called a colorimetric solid phase extractor (CSPE). "You flow 10 milliliters of water through a 1-centimeter-diameter disk of organic polymeric material, which extracts the biocide and collects it," Porter says. "The disk is preloaded with a dye that selectively binds with silver or iodine and turns color. When the disk is put into a diffuse reflectance spectrometer, it measures the color's intensity, which can be correlated with the biocide's concentration."

Porter and his co-workers are now working on a CSPE using several disks, arranged in series or parallel, preloaded with dyes sensitive to other undesirable water contaminants that tend to build up in the frequently recycled drinking water aboard spacecraft. Example contaminants include heavy metals (lead, iron) or organic materials such as propylene glycol (antifreeze) or polyvinyl chloride (a carcinogenic byproduct of plastics). With such a multitasking CSPE, one could test water for "multiple compounds with both high sensitivity and high selectivity, down to the parts-per-billion level," Porter says, with results available in about 60 seconds. In a battlefield, customized CSPEs could aid troops screening local water for the decomposition products of toxins used in chemical or biological warfare. It could also help personnel decontaminate buildings after an attack by allowing them to test the wash water residue frequently and thereby detect when the area is indeed clean again.

Ultimately, Porter and his MIC colleagues want to make a CSPE able to detect pathogenic microbes as well as biocides — something useful in homeland defense for monitoring the potability of groundwater or the safety of food (in which case "you rinse the food and analyze the rinse," Porter explains). The MIC team also envisions CSPEs' doing routine screening at reservoirs and pipes exiting water treatment plants.

The technical challenges of devising early-warning systems for compromised air, water, and food are surprisingly similar both in space and on Earth.

Safeguarding Food

From a bioterrorist's viewpoint, the food supply would be the most difficult to attack because of the

More NASA Ammunition Against Bioterrorism

credit: NASA

NASA's Virtual Glovebox allows astronauts on Earth to practice manipulating tools, equipment, and accessories for a life sciences experiment in simulated microgravity while their hands feel feedback from holding, snipping, or handling specimens. Such virtual-reality technology may prove useful in training first-responders how to handle or disarm bioterrorism weapons.

A NASA astronaut-training technology may prove potentially useful against bioterrorism. The Virtual Glovebox (VGX), developed by Jeffrey Smith, deputy director of the BioVIS Technology Center at NASA Ames Research Center in Moffett Field, California, gives astronauts a feel for what it is like to work in a glovebox in microgravity before actually doing it," Smith explains. Aboard the International Space Station (ISS), life sciences experiments are enclosed within gloveboxes with transparent plastic viewing ports. Rubber gloves attached to one wall of the glovebox allow astronauts to reach in to handle animals and other organisms, perform experimental assays, and collect biological samples without allowing air or fluids to escape into the crew cabin or air from the cabin to contaminate the controlled atmosphere inside the glovebox.

With colleagues at NASA Ames Research Center, Smith designed the VGX as a virtual-reality training environment. The team incorporated ultrahigh-resolution imaging technology with force-feedback devices and high-resolution graphics to realistically present the look and feel of tools, samples, and experimental equipment in microgravity.

When using the VGX, astronauts reach through gloves into a chamber and look down at their hands — but instead of seeing through the top of a glovebox, they are looking at a three-dimensional stereoscopic display. The movement of the gloves is tracked in the computerized virtual environment, and force-feedback devices let the astronaut feel his or her hands cutting, gripping, and working with samples as they float and tumble in microgravity.

Smith sees several potential applications of the VGX, including many against bioterrorism. The VGX "could help train handlers in specific procedures for defusing different bioweapons," Smith suggests, since "a lot of biohazardous materials are handled in gloveboxes anyway." He hypothesizes that such training could be faster and less costly using the VGX than the traditional method of setting up mock laboratories for various scenarios, as well as more flexible in responding to changes bioterrorists might make in their weapons designs. Ultimately, VGX technology also might be useful in teleoperations, where humans away from danger could control the movements of robots sent into harm's way to dismantle a biological weapon.

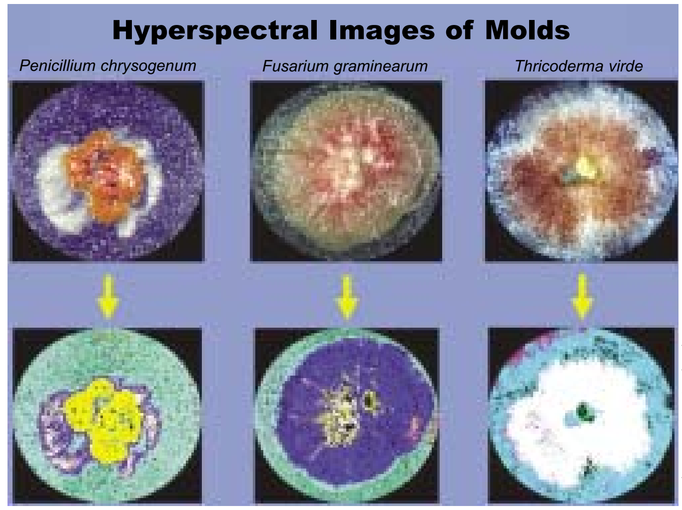
Information about NASA's Virtual Glovebox is available at *http://virtual.arc.nasa.gov/vislab/vgx.htm.*

previous administration's implementation of the strict Hazard Analysis and Critical Control Point (HACCP) system, which specifies that *every* handler in the food-processing chain, from farm to table, has legal liability for any compromise to food safety. The HAACP system means a farmer is legally liable, say, for growing crops at a contaminated site, as is a middleman for transporting raw product without proper refrigeration to a processor, all the way to a retail grocer selling goods past their shelf-life date. In the United States, the HACCP system also pertains to any foods imported from other nations.

Because of HACCP, cleanliness procedures in the food-processing industry are strict and penalties for noncompliance severe. But if it takes a day or two to culture and identify harmful microbes, how could one guard against possible bioterrorism as an "inside job" by a food-processing plant employee? Ideally, one should be able to test the cleanliness of conveyor belts and other facilities instantaneously several times a day.

Technology developed by Kasthuri Venkateswaran (who prefers to be called Venkat), a microbiologist in JPL's Biotechnology and Planetary Protection Group, could help food-processing plants ensure they are absolutely clean with no contamination. Venkat's device, an adaptation of an assay invented by Kikkoman Corporation in Japan (maker of soy sauce and other Japanese foods), relies on the fact that all earthly living organisms, single-cell and higher, rely on the molecule adenosine triphosphate (ATP) as a source of stored energy.

Traditionally, people detect microbes by swabbing an area and placing the sample in a dish of nutrient to see what grows. The problem is that "different 'bugs' grow in different nutrients, so it is virtually impossible to grow all 'bugs' at once" in one dish because "there is no universal nutrient," Venkat says. Worse, the growth may take several days — too slow for daily testing of food-processing facilities. Kikkoman's original ATP test, however, can detect ATP from *all* dead or living microbes in half a



credit: ProVision Technologies

Some molds on corn, soybean, or other food or feed products produce toxins poisonous to humans, so any crops or shipments containing more than a few infected kernels must be destroyed. A hyperspectral sensor system based on NASA remote-sensing technology, however, allows harmful molds to be differentiated quickly from harmless ones using differences in their spectral signatures (patterns of color). Here the physical appearances of three molds in petri dishes (top) are shown with their corresponding hyperspectral images (bottom).

minute; because of its speed, it was originally applied by NASA to ascertain the cleanliness of the floors, walls, and air of JPL's clean rooms, where spacecraft intended to explore Mars are assembled. Venkat's modification of the assay, however, can differentiate what proportion of those microbes are alive. (Because larger organisms contain more ATP, guessing the number of microbes from the amount of ATP in either assay is problematic.)

Both versions of the assay are roughly the size of a kitchen wall telephone. In Kikkoman's original assay, a user takes a sterile cotton swab, rubs it over 25 square centimeters (4 square inches) of the target area, and inserts the swab into 2 milliliters of sterile water. Any microbial ATP on the swab is released and immediately combines with luciferase — the same enzyme that lights up fireflies — and begins to glow. The number of photons detected is proportional to the amount of ATP in the sample, regardless of whether the ATP is from dead or living microbes. In Venkat's modification, another enzyme is first introduced to degrade the ATP from dead microbes into other chemicals (a process taking about half an hour), so that the only ATP eventually detected is that from living organisms.

Venkat is now adapting his ATP assay for detecting microbes in the drinking water used aboard the ISS to reconstitute the astronauts' food (done essentially by replacing the sterile water in the ATP assay with a sample of the drinking water). If an automated water- or air-collection apparatus is installed at the front end, he also envisions that his ATP assay could be stationed at the water intakes of reservoirs or the air intakes of buildings, and could alert early responders to unusual spikes in the total amount of ATP (and thus the total "bio burden" of microbes detected), possibly signaling a bioterrorism attack. The ATP assay could also be used by grocery stores and consumers to assure themselves of the safety of heat-and-eat foods that do not require cooking.

Because of HACCP's stringent procedures and penalties, Venkat and other sources expressed less concern about the possibility of bioterrorism in food-processing plants than about what George May, director of ProVision Technologies (a NASA research partnership center at Stennis Space Center in Mississippi), calls "agriterrorism." Agriterrorism is "anything people could do to disrupt the food or feed supply at its source" with the goal of throwing the industry into disarray rather than trying to kill consumers eating a final product, May explains.

Of some concern is the possibility of intentional contamination of crops with molds and fungi. Although such organisms occur naturally in food and feed, they can spoil a field or shipment. The Department of Agriculture specifies tolerances for certain molds and fungi in crops such as corn, soybeans, and peanuts. Currently, to ensure transported crops are within the tolerances, samples of grain from different parts of a shipment are taken to a laboratory for chemical analysis, a process requiring up to 24 hours. The analysis and related delay in shipment cost money, and if crops were tampered with could contribute to a serious disruption in supply.

Enter hyperspectral imaging (HSI), a technique JPL invented two decades ago for remote sensing satellites. HSI captures hundreds of images of a target at very close wavelengths (colors), picking up subtle changes and variations in the sample imperceptible to other techniques. May and his colleagues at ProVision Technologies have been developing compact HSI scanners that operate all the way from the ultraviolet through visible wavelengths and into the shortwave infrared for use on Earth. Specifically, they are pilot-testing a commercial device for the poultry industry that quickly recognizes the subtle difference in the spectral signature (wavelength composition) of light reflected off a raw chicken carcass that is clean versus one contaminated with fecal matter. The key word is "quickly," May says, because an assembly line in a commercial poultry factory passes by the HSI scanner "at the rate of 70 birds a minute, giving less than a second for each test."

Responding to fears about agriterrorism, May is now adapting HSI to identify various molds that attack grains and other crops. May's goal is to develop a dipstick-like probe that could be pushed down into different places in a shipment of grain and give instantaneous readings as to the presence or absence of harmful molds.

Easy Use = Tall Challenges

For equipment both to advance the frontiers of science in space and to be useful in checking bioterrorism on Earth, the laundry list of technical requirements (compact, low-power, etc.) is monumental. "The detector and sensor are the *easiest* parts," declares John Hines, technology development manager of the Fundamental Biology Research Program at NASA Ames Research Center in Moffett Field, California. "The hardest parts are preparing the sample without human intervention, and miniaturizing and automating the complex analytical process."

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From Exotic to Ubiquitous: Innovative Technology May Make Plasmas Part of Our Lives

By creating plasmas that remain stable in air, a team of NASA-funded scientists has developed a new tool that may soon fight pollutants, airborne diseases, and bioterrorism — as well as support long-term space missions.

Plasmas have always sounded a bit, well, exotic. Even their common descriptor, "the fourth state of matter," suggests they are less common than the three traditional states — solids, liquids, and gases — seen every day. Yet plasmas are ubiquitous. They make up the Sun, stars, nebulae — in fact 99 percent of the visible universe. On Earth, they shimmer in the aurora borealis and crackle in lightning and flames. And thanks to a NASA-funded innovation led by George Korfiatis of Stevens Institute of Technology in Hoboken, New Jersey, plasmas are about to play an important role in everything from purifying air on long-term space missions to fighting bioterrorism on Earth.

Plasmas are neither solids, liquids, nor gases. Instead, they are highly energetic mixtures of electrically charged atomic particles created by injecting energy into matter. Lightning, for example, occurs when an electrical discharge from a thunderstorm splits air molecules into a swirling plasma of positively charged ions and free electrons. Because of the free electrons, a plasma is an electrical conductor, forming a virtual wire for the electrical discharge to flow to Earth as it seeks a ground.

The neon lights that ornament Broadway are glowing plasmas in glass tubes. High voltages ionize neon (or argon or krypton) gas by energizing electrons so they jump farther away from the nucleus. When they drop back to their original position, they release a photon of red light. Fluorescent lights in offices and factories are based on a similar principle, but the photons they release activate phosphors that emit white light.

More recently, researchers have used plasmas to do innovative chemistry. Because they are free and energetic, plasma ions and electrons are highly reactive and readily initiate chemical reactions when they contact other molecules. The semiconductor industry, for example, uses plasmas to etch trenches and holes in silicon wafers, and to break apart large molecules into pieces that reassemble as electronic thin films.

Lightning, a well-known form of atmospheric plasma, consists of free electrons that carry electrical discharges from thunderclouds to ground on Earth. Atmospheric plasmas typically last only a fraction of a second. Breakthrough science has enabled George Korfiatis and fellow researchers to create plasmas that remain stable for long periods of time.

Fragile

Highly reactive chemistry has tantalized researchers for decades. They envisioned running refinery, petrochemical, or power plant emissions through a plasma, whose high-energy charged particles would react with pollutants, breaking them down into more benign chemicals.

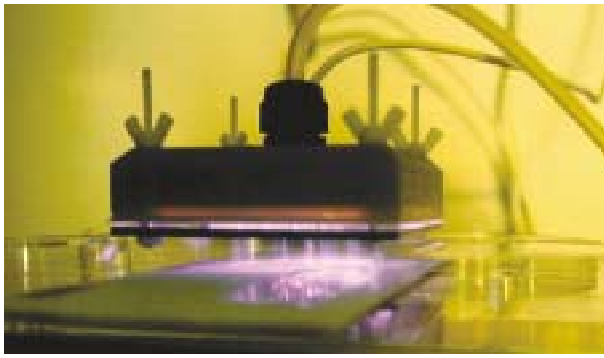
The problem, though, is that plasmas are fragile, unstable creatures. They thrive in the partial vacuum of an enclosed neon light or semiconductor chamber. Leave them at atmospheric pressure, however, and they react with surrounding air molecules, arcing to ground. Like tiny flashes of lightning, which they resemble, they burn away the surface of the equipment generating them. As a result, most plasma chemistry is done under a vacuum using highly diffuse plasmas. While that works wonders on a 300-mm semiconductor wafer, it would never pass muster in a 3-meter factory smokestack.

To take full advantage of plasma chemistry, researchers needed to create a dense, low-temperature plasma that could work in air. But how?

Serendipity

A string of events involving three researchers at Stevens Institute of Technology, Korfiatis, Erich Kunhardt, and Kurt Becker led to the answer.

In the mid-1990s, physicist Erich Kunhardt began using electrical discharges to create cool, stable plasmas in tiny holes, or capillaries. "I really liked the idea of a



credit: NASA

Korfiatis, Kunhardt, and Becker have launched a new company, PlasmaSol Corp., to commercialize cold plasma. Here, a PlasmaSol research system produces an atmospheric plasma discharge that looks like small bolts of lightning with one critical difference: it remains stable in air over long periods of time.

hole and grid structure," he recalls. By distributing the plasma over a large grid of holes, he hoped to keep the plasma created in any individual hole from reaching the critical point where it would arc.

Becker, meanwhile, had been working with ion detectors, notably a device called a thyrotron, which consisted of thousands of micron-sized holes drilled into an insulating plate. Thyrotons have a very unusual property: "When you try to push too much current through them, they shut off," says Becker. By placing the thyrotron in front of a plasma discharge, Becker and Kunhardt hoped to distribute the plasma over thousands of capillaries while suppressing the arcs that destroyed plasma equipment operating in air.

Kunhardt and Becker scavenged equipment from engineering labs around the campus to build their first device. Surprisingly, it worked right from the start. They had developed a dense, cool plasma that worked in air.

Opportunity NOx

The next step forward came in 1995. Kunhardt, who was hosting a meeting on ionized gases, asked Korfiatis, a noted environmental researcher, to chair a session on environmental uses of nonthermal plasma. While Korfiatis had a general knowledge of the subject, preparing for the meeting opened his eyes to detailed possibilities. It also introduced him to Kunhardt and Becker's cool, dense, open air plasma.

What Korfiatis saw was something that acted like a fire, but with significant differences. First, it was far more efficient. "Instead of imparting energy into bulk space, plasmas impart energy only to the molecules they interact with," he explains. The new atmospheric plasma also operated at low enough temperatures to clean a plastic surface without burning it, or to sterilize a circuit board without melting the solder.

Because plasma energies are very controllable, Korfiatis thought he could use them to chemically react with some molecules while ignoring others. He points to the family of nitrogen oxides (NOx), pollutants associated with global warming and acid rain, as an example.

Ordinarily, says Korfiatis, most air is made up of paired oxygen atoms (O_2) and paired nitrogen atoms (N_2). Combustion breaks their molecular bonds, creating ions. As they cool, most oxygen ions recombine with another oxygen to form molecules. Most nitrogen does the same. But some oxygen and nitrogen combine with each other to form NOx.

Environmentalists have tried to control that smog-producing reaction for decades. They know it takes far more energy to split nitrogen molecules than oxygen molecules. So they have tried to suppress combustion heat by spraying power plant furnaces with fine mists of water or using less efficient leaner burns in internal combustion engines.

These strategies have had limited success because combustion is difficult to control, says Korfiatis. Instead, he wondered, why not create a plasma with just enough energy to split oxygen molecules while leaving nitrogen molecules untouched? Initial results suggest that the plasma approach is valid.

Long-Term Survival

But in 1995, cold plasma was not quite ready for prime time. Kunhardt and Becker were still operating in their laboratory and had not yet tried to optimize their equipment for specific applications. Nor had they ever used their system for selective reactions.

Enter NASA's Office of Biological and Physical Research, which provided some of the early funding that made this work possible. NASA's interest stemmed from its concern about volatile organic compounds (VOCs), which include potentially toxic chemicals. Aboard the International Space Station (ISS), very small amounts of VOCs are released over time by the plastic panels and foams as well as the thermal control system. On Earth, such minute concentrations would go unnoticed as air moved through a home or office. Aboard the ISS, however, the same air recirculates again and again. As a result, VOC concentrations rise over time.

Long-term space missions pose more serious problems because of the need to grow food inside spacecraft. Growing plants emit all kinds of gases, Korfiatis explains: "Ripening fruit emits ethylene, and the aroma from leaves and stems is all due to volatiles."

Systems aboard the ISS now remove trace VOCs by either breaking them down with high-temperature catalysts or adsorbing them onto activated carbon. On long-term missions (say, to Mars), however, it is unlikely there will be spare energy for high-temperature catalysis, and contaminants are likely to saturate an activated carbon bed early into the mission. But cold plasma could break down volatiles either as they circulate through the spacecraft or on the activated carbon bed, using little energy.

Sterile Environment

Cold plasmas also could sterilize spacecraft. "The minute you introduce living entities into a space ship with warm, moist air, you have a thriving microbial population," says Korfiatis, pointing out how the portholes aboard the *Mir* were fouled with algae.

Years-long missions in closed environments raise serious concerns. "There are lots of harmful things you could take with you, such as spores and bacteria," Korfiatis explains. Even organisms that start out benign might mutate after long-term exposure to solar radiation. Imagine, for example, bacteria that find a home in circuit boards or heating and cooling systems.

"We need to have something on board to sterilize surfaces and kill airborne spores and bacteria," says Korfiatis. Cold plasma does that efficiently. First, the electric discharge creating the plasma breaks down air molecules into many highly active materials — atomic oxygen, ozone, hydroxyls — that are themselves disinfectants. Second, the electrical discharge itself creates ultraviolet rays, which also attack microbes.

Cold plasma may also help in the search for life on other planets. NASA researchers worry that a stray Earth microbe could contaminate probes to other planets, creating false positive readings. Cold plasma could sterilize an entire spacecraft without damaging plastic and electronic parts.

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Research Update: Fundamental Space Biology

Probing the Inner Universe of the Mighty Macrophage

The macrophage is a white blood cell critical for our defense against infection and skeletal well-being. Understanding the behavior of macrophages in microgravity could lead to treatments for immune and bone disorders, and help astronauts remain healthier on long spaceflights.

For cell biologists, the inner space within the boundaries of cellular membranes holds as many unanswered questions and places for exploration as the distant reaches of outer space. One type of white blood cell, known as the macrophage, has particularly captivated NASA investigator Stephen Keith Chapes, leading him beyond Earth's atmosphere to probe the cell's inner secrets.

credit: Joseph Chapes

Stephen Keith Chapes stands in front of the Space Hardware Optimization Technology (SHOT) CellCult Bioreactor and Advanced Separation (ADSEP) Processing Facility hardware, a fully automated cell-culture system to be used during spaceflight to study how human immune cells called macrophages develop in microgravity. The ADSEP hardware grows bone marrow stem cells in a controlled environment for 7.5 days, to preserve how stem cells in space morph into macrophages compared to ones on Earth.

What is interesting about macrophages? Well, they do have busy workdays. Macrophages are part of an individual's early defense mechanism, and act as cellular garbage disposals by gobbling up spent red blood cells. They also respond to the daily torrent of pathogens by wolfing down bacteria and by carrying foreign proteins to cells that make antibodies. In fact, macrophages link the fate of the immune system and the fate of the skeleton by producing cytokines, immune proteins that perform double-duty by fighting infection and promoting skeletal health.

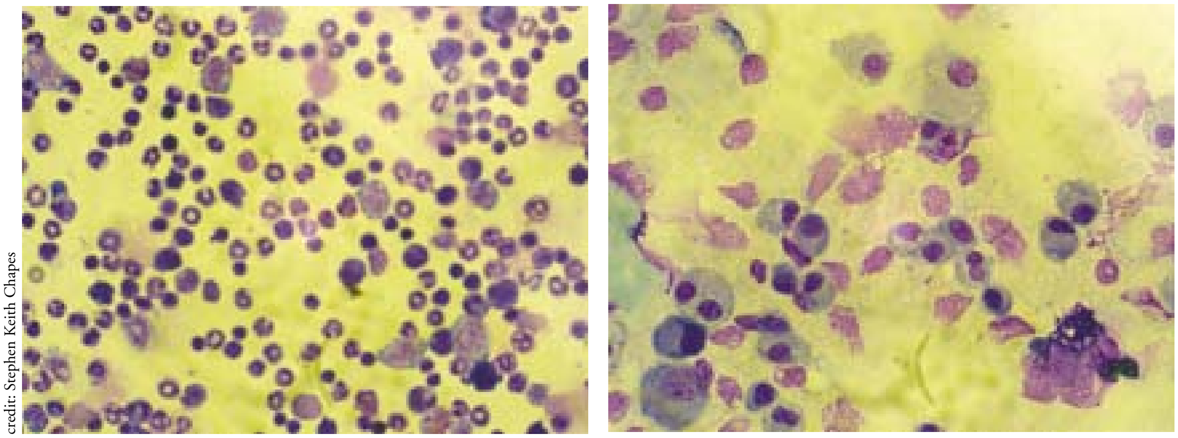
While scientists understand the macrophage duty roster, these cells still hold abundant secrets. Only in the late 1990s, for instance, did researchers discover that macrophages could, with the addition of a certain protein, continue down the differentiation pathway to become osteoclasts, one of two types of bone cells critical for maintaining skeletal strength. That research spawned the discovery of new receptors on the surfaces of macrophage cells and new pathways inside the cells — work that continues today. Chapes, a biology professor at Kansas State University in Manhattan, is contributing to new discoveries in macrophage biology by using microgravity as a research tool.

From Stem Cells to Macrophages

It is well-known that red blood cells do not develop as well in microgravity as they do on Earth. But scientists know less about the fate of other cells such as macrophages in the near absence of gravity. That is why Chapes and his team are studying how macrophages grow from stem cells, formative cells found in several tissues such as the spleen and bone. Stem cells, depending on the chemical signal, morph into mature white blood cells, such as lymphocytes and macrophages. In microgravity, if stem cells cannot differentiate and become mature macrophages, the immune system and the skeleton will be compromised.

Like other blood cells, macrophages are made in the bone marrow during what is called hematopoiesis, a process during which stem cells progress through a series of changes in biochemistry, structure, and metabolism that transform them from immature cells indistinguishable from one another to an array of highly-specialized cells. Macrophages are formed by dividing and differentiating through a complicated pathway that creates both immature cells called monocytes (which leave the marrow and patrol the blood stream) and macrophages (which take up residence in tissue as mature cells). Scientists already know that prolonged spaceflight or long bed rest weakens the skeleton, and any changes to the skeleton could weaken the marrow as well. When hematopoiesis is disrupted, every tissue in the body is at risk.

"I like to think that if you impact hematopoiesis you are going to impact the host's ability to resist insults," explains Chapes. Among the many problems with space, continues Chapes, "Spaceflight is chock-full of insults. You are exposed to changes in pressure. You are exposed to an environment where aerosols and particles will [remain suspended and do not fall out] because there is no gravity so you inhale



credit: Stephen Keith Chapes

Bone marrow cells have been stained purple with a special dye and photographed at 40 times magnification under a microscope. Stem cells (left) from bone marrow before they have been grown in the culture hardware are uniformly small and circular. Cells after they have specialized and become macrophages (right) are larger and elongated. Since macrophages respond to microgravity in about 8 seconds by changing shape, Chapes and his group are also investigating how spaceflight might induce molecular changes inside the cells.

them. You are exposed to stress from being in a new environment." Also, he says, the body's circulation isn't quite normal because in microgravity blood redistributes towards the upper body instead of pooling toward our feet as it does on Earth.

Many factors in the space environment can compromise the health of astronauts. Hematopoietic stem cells would be more susceptible to radiation damage if they were actively dividing, a situation that could be worsened if space increased cell division, says Chapes. Also, poor circulation and dust-filled air could add up to health problems if fewer mature macrophages patrol the lungs and nibble away at foreign particles. "Nobody has ever gotten so immunologically compromised [in space] that they're sick, but that doesn't mean there isn't an impact on the immune response," remarks Chapes.

Chapes knows from his ground-based research that genetically engineered mice lacking functioning macrophages are susceptible to microorganisms normal mice can fend off. Chapes also notes that several types of mice lacking macrophages also lack osteoclasts. Without osteoclasts around to hold up their end of skeletal remodeling these mice have osteopetrosis, a condition characterized by an overabundance of bone that is very brittle. If these observations of mice also hold true for people in microgravity, it might be difficult to keep astronauts healthy during prolonged exposure to the microgravity environment.

Macrophages in Microgravity

In 1987, Chapes and his group began to focus on how spaceflight affects the immune system. Experiments using macrophages in parabolic flight (see sidebar) revealed that macrophages respond to microgravity in less than 10 seconds after exposure to microgravity.

Investigations on several space shuttle flights revealed even more. For some experiments, he grew macrophages in "space test tubes" placed in special hardware and after the flight examined them in his laboratory. For other experiments, he flew rats to study changes in their bone marrow stem cells back on Earth. The results were significant: although marrow precursor cells divided better in microgravity than they did on Earth, they would not differentiate. "This led me to speculate there might be a direct effect of spaceflight on macrophage progenitors," explains Chapes.

Today, Chapes is preparing an experiment that will pinpoint at the molecular level where this defect in macrophage development occurs. This experiment was originally scheduled in May on the *Endeavour*, before all space shuttles were grounded following the destruction of the *Columbia*. On a future space shuttle flight, he will grow undifferentiated bone marrow precursors from mice and set up parallel experiments in his laboratory on Earth. In the first phase of the experiment, cells will be loaded into Space Hardware Optimization Technology (SHOT) CellCult Bioreactor and Advanced Separation (ADSEP) Processing Facility hardware, a fully automated cell-culture system. The cells will be kept at a low temperature, which will hold them in "neutral" until the experiment is ready to begin in microgravity. Once in orbit, an astronaut will flip a switch and the cells will be heated to 37 °C, or 98.1°F, snug warmth that mimics body temperature and encourages growth. The hardware automatically adds macrophage (CSF-1), a cytokine that pushes bone marrow stem cells along the differentiation pathway until they become mature macrophages. At the end of 7.5 days, plenty of time for marrow cells to mature, a fixative will be added to preserve cells for study on the ground.

Molecular Questions

After the space shuttle returns, both Earth-grown and space-grown cells will be analyzed for changes both inside and outside the cell membrane.

Chapes will first look for changes on the outer surface of the cell membranes at receptors, molecular "docking places" on inner and outer cell membranes where cytokines such as CSF-1 can bind and bring about some change in the cell. Once CSF-1 is bound to the receptor, a signal travels through an intracellular pathway telling the differentiation machinery to work. If c-*fms*, the receptor for CSF-1, is not working — or if fewer receptors are

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Cells on a Wire

In one set of experiments, Chapes asked whether microgravity affected macrophages and if so, how quickly. He and his group set up an experiment on NASA's KC-135 aircraft, which creates about 25 seconds of microgravity during the free-fall portion of parabolic flight. They placed macrophages on a silver electrode and passed a current through the wire. If the cells changed shape, that change could be measured as a change in resistance.

Just 7–10 seconds after the KC-135 entered its first freefall, the cells stayed attached to the wire and flattened out. When the aircraft returned to 1 *g*, the cells rounded back up.

Chapes wants to investigate the significance of this quick reaction to microgravity. For now, he knows that macrophages, stretchy cells to begin with, react quickly to the change in gravity.

Solidifying the Future

Scientists use microgravity, where buoyancy is minimized, to see how bubbles form and move within molten metals and alloys as they solidify.

The beautiful structure of a snowflake is a well-known example of the way tiny water droplets freezing into ice form branching crystals. Such branching crystals are called "dendrites" from an ancient Greek word for tree. As a puddle freezes, however, a continuing dendritic network of ice crystals forming across its surface traps air within the water, bubbles that remain when the puddle is frozen solid.

Many metals and alloys also have dendritic structures. When molten metals or alloys are solidified for commercial applications, uniformly distributing the dendrites and controlling or eliminating gas pockets are crucial to ensuring the materials' strength.

Richard Grugel at Marshall Space Flight Center, investigator for the Microgravity Science Glovebox (MSG) on the International Space Station (ISS), is seeking to understand the subtle forces that act on gas bubbles in molten metals and alloys. Grugel and his team have created the Pore Formation and Mobility Investigation (PFMI) to study how bubbles move and interact with one another as a material is melted and solidified in microgravity.

Gravity and Bubbles

On Earth, when a metal is liquid, gravity-driven buoyancy dominates the movement of any bubbles that form, often causing them to rise quickly to the surface, pop, and disappear. But as a metal cools, bubbles can get trapped between dendrites forming in the bulk of the material or under the solidifying skin on top of a casting. Such bubbles become pores: trapped pockets of gas that diminish the material's usefulness.

Gravity-driven buoyancy so dominates the behavior of bubbles on Earth that it hinders scientists from observing slighter influences on their dynamics — and thus from possibly discovering other clues to the causes of porosity. In microgravity, however, buoyancy is minimized: bubbles do not rise and disappear, allowing for an in-depth study of their subtler behavior.

Grugel hopes that data from his PFMI experiment will be useful in designing future microgravity investigations, as several previous materials-processing experiments in space resulted in bubbles trapped within the solid. He also hopes PFMI will provide insight toward understanding the dynamics of bubble interactions during materials processing in Earth's gravity.

At Work on the ISS

The PFMI apparatus flew to the ISS with the Expedition 5 crew aboard space shuttle mission STS-111 in June 2002. The PFMI thermal chamber, the experiment cameras, and other data-collecting devices were installed in the MSG, a rack-sized, enclosed working volume that allows astronauts to conduct experiments in a contained environment.

At the heart of the PFMI are 15 samples containing succinonitrile (SCN), a transparent plastic-like material with a low melting point commonly used to model and directly observe melting and solidifying processes that occur in metal alloys. Five of the samples are pure SCN; the other 10 are mixed with less than 1 percent of water to simulate alloys. (An alloy is composed of at least one metal; the samples used in PFMI are better described as a mixture of two compounds, but their behavior is very similar to that of an alloy.) Because water acts as an "alloying" agent, "we will definitely see more dendritic-type structures in these samples," says Grugel.

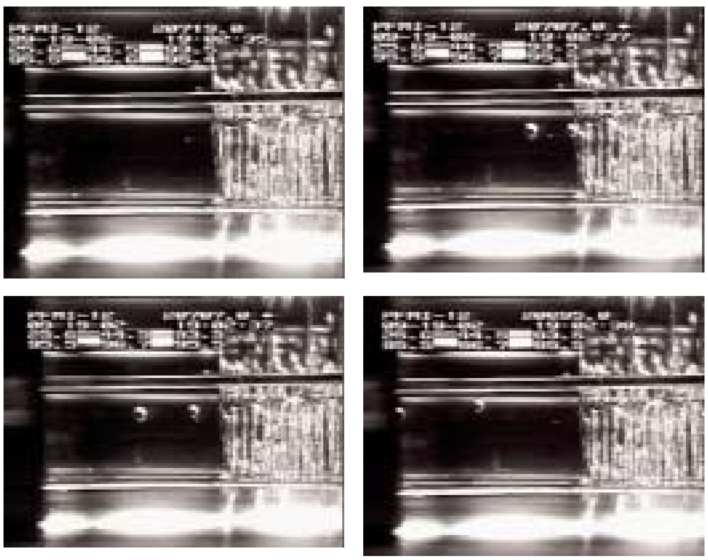
The samples are preloaded in customized glass tubes 1 cm (0.4 inches) in diameter and 20 cm (7.9 inches) in length.

credit: NASA

Taking a closer look at the liquid/solid interface, a network of branching dendrites form into a succinonitrile-water sample like a preliminary skeleton for the solid to take shape. This video image shows tiny bubbles trapped within the crystal branches, a problem sometimes encountered in materials processing on Earth. In its melting and solidifying, the succinonitrile-water sample mimics the behavior of metal alloys.

Running along the inside of the filled tubes are six thin protective metal sheaths of increasing length, each of which contains a thermocouple that continuously measures the temperature in the sample during processing. (A thermocouple is a wire made of two dissimilar metals bonded together; heating induces a voltage difference that is a sensitive indicator of temperature.) Inside the far end of the tube is a compression spring and piston that exert a constant pressure on the sample to eliminate any gaps that might develop as the material expands during melting. Two video cameras record the sample's behavior in the thermal chamber during each 10- to 12-hour experiment run.

Similar to the commercial process for making turbine blades, PFMI uses a process called controlled directional solidification. As each experiment begins, a heating and cooling mechanism that surrounds the glass tube slowly moves along it in one direction and heats the sample to a maximum of 130 ˚C (266 ˚F). Pure SCN melts at 58 ˚C (136 ˚F) and the SCN-water compound melts at about 55 ˚C (131˚F); the extra heat is used to establish temperature gradients along the sample. As the sample is heated, the formation of bubbles and their behavior within the melt are observed and recorded. After the melting cycle is completed, the surrounding mechanism begins its cooling cycle and the direction of its movement along the tube is reversed. Thus the molten sample is re-solidified under controlled conditions. "During re-solidification of the SCN-water mixtures, aligned dendrites form and we have observed bubbles generating between them," says Grugel.


credit: NASA

This series of photographs from an International Space Station experiment conducted in September 2002 shows melting solid pure succinonitrile (on the right of each image) and bubbles being released into the liquid (on the left). According to theory, two prime factors determining bubble movement are the temperature gradient in the liquid ahead of the solid and the size of the bubble. The numbers in the top left corner represent (from left to right) sample number, position, date, time, and the six temperatures collected from the thermocouples, which are the horizontal lines.

Various Variables

Grugel explains that there are three main processing variables: "alloy composition, the growth velocity of the solid, and the temperature gradient in the molten material ahead of the solid." How those variables affect the solid's microstructure is essential because they are what determine the material's strength and other properties. For PFMI, Grugel is primarily concerned with the growth velocity and the temperature gradient.

"The growth velocity," explains Grugel, "is the rate at which the molten material solidifies." A minimum growth velocity is needed for dendrites to form; moreover, different growth velocities create specific dendritic patterns. The faster the molten material solidifies, the finer the dendritic pattern that results. A finer microstructure generally yields better mechanical properties. Collectively, the dendrites are essentially a framework for the solidifying material, influencing its structural strength. "Hopefully, the experiment's data will be useful in mathematical models, with the intent of eventually being able to tailor specific material properties during solidification," says Grugel.

The temperature gradient in the molten material ahead of the solidifying material also affects the movement of bubbles. With buoyancy effects minimized in microgravity, bubbles might not be expected to move through the liquid. However, any subtle effects acting on a bubble that are normally masked by Earth's gravity are revealed in orbit.

"Our experiment is set up so that for a few centimeters the temperature of the liquid increases as it moves away from the solid," explains Grugel. "Thus, when a bubble is released from the solid, its leading side into the liquid is slightly warmer than its rear." The imposed temperature gradient across the bubble affects molecules on its surface and causes a flow on the bubble's surface that usually moves the bubble from cooler to warmer temperatures, something that buoyancy forces overwhelm in Earth's gravity.

"We have directly observed that when bubbles leave the solid and move up the temperature gradient, they stop when the temperature of the surrounding liquid is the same as that of the bubble," says Grugel. "These results, obtained under dynamic conditions, could only be observed in microgravity" and should be highly interesting when compared with theory. Grugel believes the results could be useful to materials processing both in microgravity and on Earth.

Results to Build On

The first PFMI experiment in microgravity was conducted in September 2002. Grugel and his team of investigators occupied the Telescience Center (TSC) at Marshall's Microgravity Development Laboratory, watching snatches of video from the experiment every 5 to 15 minutes. When the ISS was above the horizon, they also sent commands to the experiment, changing the temperature, growth rate, and other variables.

"The video downlink from the station during the runs was essential to conducting the experiments," says Grugel. "We are very pleased with the results. The entire set of real-time videotapes for the completed samples were brought back with STS-113 in December 2002, and is being analyzed."

Between September and December, eight samples were tested, two experiment runs prematurely ending about halfway through processing due to anomalies (one a "single event upset" in the PFMI motor control that was quickly restored, the other when the MSG lost power). Still, Grugel says he is pleased with the MSG as a research facility. The MSG has well demonstrated its capability, and Grugel believes its generic design makes it a potential candidate for future investigations. "For relatively low cost, we are getting good value out of the glovebox," Grugel says. "The station crew has been very accommodating. Also, I cannot give enough credit to our small but dedicated and talented ground-based team."

Grugel reports that he and his colleagues are evaluating the data they have so far to get quantitative measurements and compare the findings with current theoretical models. "I suspect that upon careful examination of the tapes we will get more than we expected about the dynamics of bubbles and solidification under controlled processing conditions in microgravity," says Grugel.

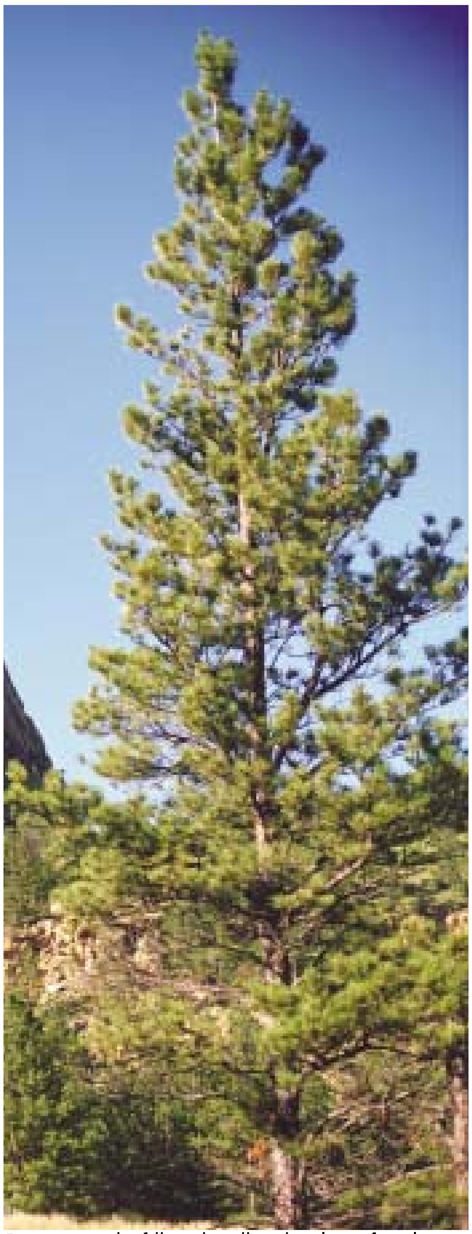
Chris McLemore

For more information about the PFMI study go to *http://www1.msfc.nasa.gov/NEWSROOM/background/facts/PFMI.html*.

Lowering Lignin Levels: Key to Stronger Paper Industry

Reducing a tree's level of lignin, a polymer that provides structural support and other valuable services to plants, could make paper production more economical and environmentally friendly.

It is no secret that the pages on which these articles are printed started as trees. What one may rarely consider, however, is the complex, expensive process needed to turn rigid wood into pliable paper, which remains in high demand despite the revolution of the electronic age. The process for producing paper includes several caustic chemicals necessary to remove lignin, a tough, poorly understood polymer.



Trees gain much of their strength and resiliency from lignin, a natural polymer that must be removed when trees are pulped for paper production.

Lignin gives trees much of their strength and natural resiliency (it is virtually indigestible and hard to burn). Lignin also serves in the vascular transport of water and nutrients from roots to leaves and in the defense against infection, activities that are essential for normal growth and reproduction. However, its presence and resiliency hinders the process of making quality paper.

But what if you could grow trees that possessed a lower lignin content? The cost of paper manufacture, and its environmental impact, could be significantly reduced. That is the objective of lignin investigations conducted by BioServe Space Technologies, one of NASA's Research Partnership Centers, in Boulder, Colorado, and its partners including Weyerhaeuser, an international lumber and paper company based in Federal Way, Washington, and the U.S. Department of Agriculture's Forest Products Laboratory. This consortium is focused on improving timber and subsequent paper quality through research in plant cell walls, lignin, and cellulose, another structural polymer in plants.

Following the Right Trail

"The lignin content of timber is generally not an issue," explains Gerard Heyenga of NASA Ames Research Center and BioServe. "Lignin becomes an issue only when you want to pulp timber for paper. You have to bleach it out with pretty noxious salts and a large amount of water." Although the industry tries to recycle as much of the chemicals as possible, wastes inevitably wind up in the environment.

Researchers want to know how to reduce lignin that functions as structural support without reducing lignin that helps nourish and protect the tree. Scientists have tried various techniques in genetic selection or manipulation of genes associated with the production of lignin, but they have achieved only limited success. Some investigators have "knocked out" genes in test plants, hoping to alter lignin production, but the results are uncertain. Further, the knockouts could hamper *all* lignin production rather than simply making a lighter structure.

"At this stage of our knowledge, we do not know which set of genes regulates vascular development, structure, or defense," comments Heyenga.

It is probable that lignin was first used in terrestrial plants as a "structural" countermeasure to the force of gravity. It is only with the increase in plant stature over evolutionary time that the baseline content and additional roles for lignin increased to the level presently found in tall stature plants such as trees. Figuring out the control mechanism that governs structural lignin in tree species by regressing back to an earlier evolutionary state is certainly an approach, however, removing the force that may have induced it in the first place, namely gravity, could be more effective.

"My work is directed at researching the intriguing question, 'what happens when plants are no longer subjected to the force [or stress] of gravity?'" Heyenga explains. "In the absence of gravity's effects, will plants perceive they no longer have a mechanical load to support? And will plants respond by decreasing the production of structural lignin without impacting the production of lignin used for other important functions, which are essential for normal plant health?"

If the plants down-regulate production of structural lignin during orbit, as Heyenga and BioServe expect, the next challenge will be tracking down the genetic control mechanisms and all the biochemical pathways that are involved with lignin to see how the down-regulation occurs.

Down on the Factory Floor

Those genetic mechanisms take scientists to the biochemical pathways, where cells are robotic factories assembling high-tech products. Key to all the activities is messenger ribonucleic acid, or mRNA, produced by deoxyribonucleic acid (DNA), the master blueprint stored in the nucleus. The mRNA acts as a template that lets ribosomes, the production centers on the cell's molecular factory floor, assemble the proteins, which in turn synthesize the buildings blocks for products such as lignin.

"The production process for the lignin building blocks is complex," explains Heyenga, "with metabolic pathways and this whole string of related production lines. But how the building blocks of these products are transported is just as complex."

"Lignin is an intensely heterogeneous polymer," unlike the simple repeating patterns of plastics, Heyenga says. The source materials are three alcohol-base acids, called monolignols. "We are looking at their production to learn whether they are being made as much in microgravity" as they are in trees in Earth's gravity. The key to controlling lignin production may lie in the monolignols, or in transport of various compounds through the cells, and Heyenga's research could help determine whether this is the case.

"The research got a terrific start on STS-77 in 1996," Heyenga says, "when we established the protocol to grow plants in spaceflight conditions." The mission demonstrated a prototype of the Plant Generic Bioprocessing Apparatus (PGBA), which allows plants to grow in precisely monitored conditions that can be mimicked on Earth. PGBA is a miniature ecosystem that controls and measures temperature, humidity, gas mixtures, and light. It allows scientists to replicate conditions on the ground so the main variable in the ground-based and orbiting experiments is the level of gravity. Heyenga says that radiation levels may vary, too.

A prototype of the PGBA also flew on the first Microgravity Science Laboratory mission (MSL–1, STS-83 and -94, 1997) and helped stimulate commercial interest. MSL–1 carried eight plants representing

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Advanced Astroculture Update

credit: NASA

Soybean seedlings grown in ADVASC on the ISS get a close inspection before their return to Earth.

Finally, eight soybean plants were grown aboard the ISS during Expedition 5 in 2002. The seeds were of a common variety called 9306, provided by WCSAR's partner, Pioneer Hi-Bred International, Des Moines, Iowa, a subsidiary of DuPont Co. Of the eight, six were well-developed and yielded 84 seeds from 42 pods. One failed to germinate and one was ill-developed. "They grew in the same environment," Zhou explains. "The discrepancy was due to differences in seed quality," something normally experienced on the ground.

Lignin is not the only plant component that NASA and its commercial partners are investigating for possible changes due to microgravity. The Wisconsin Center for Space Automation and Robotics (WCSAR) in Madison is working to determine whether microgravity can help scientists enhance the food value of soybeans and other plants.

Weija Zhou, principal investigator and WCSAR's director, reports progress along three fronts in their investigations using ADVASC, the Advanced Astroculture™ plant growth unit. The first significant advance was seed-to-seed cultivation of *Arabidopsis* (mustard-family) plants aboard the International Space Station (ISS). From 91 original seeds that grew into plants in microgravity, WCSAR and Space Explorers Inc., a Green Bay, Wisconsin educational company, harvested thousands of seeds. The activity involved students in grades 8–12 at more than 2,000 schools around the country, each growing ground-control seedlings under various conditions and comparing their results via an Internet-based classroom.

Next, many of those space-grown seeds (plus Earth-grown seeds) were returned to space for another round of growth experiments that yielded the first batch of second-generation space seeds. Specimens were also harvested and preserved during the flight to preserve tissue and ribonucleic acid for post-mission analysis.

The seeds and plants are currently in the third of four analytical steps. The first step, morphological analysis, was measuring the shape and structures of the roots, stems, and other parts, which so far all appear normal. The next step was germination, planting some of the second-generation space seeds and seeing how they grow. "Right now those plants are healthy and will produce another generation on Earth," with a germination rate of close to 90 percent, Zhou says. "That indicates that the seeds produced in space are healthy. If the second generation had a low germination rate, you might question whether the seeds developed in a healthful way." It is slow going because the growth cycle for a soybean plant is about 120 days.

The third step, chemical analyses, will take even longer because it involves detailed analyses of the seeds and plants. Zhou says Pioneer Hi-Bred is interested in the production of certain oils, proteins, and carbohydrates that determine the value of soybeans as foodstocks. WCSAR is looking at aspects of fundamental biology, too, such as differences in estrogens and other interesting chemicals that help control the soybean's metabolism.

The chemical analyses lead into the fourth stage — genetic stability — that determines whether space-altered plants are commercially viable. Producing an oddity in space is one thing. Having a beneficial genetic variation that is handed down to the next generation and beyond is something else.

Revitalizing Education Through NASA Explorer Schools

Beginning this year, NASA is offering a unique three-year partnership to selected schools that will stock America's classrooms full of exciting learning adventures in science, math, engineering, and technology, and will provide teachers, students, and parents with valuable intellectual resources.

Capitalizing on the inherent excitement about space, NASA has kicked off a new research-based program that will enrich science education efforts in the classroom. The NASA Explorer Schools (NES) Program, sponsored by NASA's Office of Education, provides professional enhancement for teachers, high-tech lessons for students, and opportunities for parents to share the fun of learning with their kids.

One goal of this three-year partnership program, which was initiated in February 2003, is to advance scholarly growth for educators in science, math, engineering, and technology. Besides receiving a steady stream of educational technology-based lessons, NES educators will receive an all expenses paid week at one of the 10 NASA field centers where they will participate in professional development, become acquainted with NASA educational resources, and get the chance to customize their own curriculum.

A second goal is "to inspire the next generation of explorers . . . as only NASA can." NES is designed to engage students in applying math and science skills to authentic NASA data to solve real-world science, engineering, math, and technological problems. Meanwhile, students will also gain experience with such useful technology tools as graphing calculators, hand-held computers, temperature sensors that plug into their computers, and other devices. Further, students will practice skills in observation, solving equations, and writing. In short, they will gain hands-on experience related to current careers in math, science, engineering, and technology.

"We want to highlight the methods NASA scientists use while conducting research," says Peggy Steffen, NES Program Manager at NASA headquarters in Washington, D.C., "and allow students to use those same methods on their own." Steffen believes NASA's applied science, math, engineering, and technology are very intriguing to students as "some of the supplemental curriculum materials apply math and science derived from past and current NASA missions." For example, students can point EarthKAM, a digital camera onboard the International Space Station, toward their local area on the planet. Then, using the space station's trajectory and speed, the students can apply math skills to find the right time to snap a picture.

See Learning in a Whole New Light

NASA Explorer Schools 2003

http://explorerschools.nasa.gov

The NASA Explorer Schools Program equips students, educators, and parents with tools that make studying science, math, engineering, and technology more exciting. (Logo shown above.)

Getting Connected

In the summer of 2002, the Office of Education established NES as a new initiative for fifth through eighth grade to have a deeper impact on schools. The NES Program is sponsored and implemented by NASA through a cooperative agreement with the National Science Teachers Association (NSTA). Other professional partners include the International Technology Education Association, the National Council of Teachers of Mathematics, and the National Council for Geographic Education.

NES has chosen 50 middle schools from more than 400 applications, to participate for the upcoming three school years. For this pilot phase, Steffen says, "We are targeting grades 5–8, but lower grades also can be involved. It is widely believed that capturing a student's interest in science, math, and technology in middle school greatly influences his or her future classes and career choices." The selected schools are receiving a commitment for a three-year partnership with NASA. The partnership includes eligibility for a grant of up to $10,000 for updated computer and laboratory equipment, and recognition as an Explorer School.

The application process was comprehensive. Educator/administrator teams

OBPR Plans to Prime Teachers in Research in a Microgravity Environment

As NASA field centers immerse teachers in rich learning experiences this summer, the Office of Biological and Physical Research (OBPR) will introduce teachers to microgravity research and its applications that benefit human existence.

Specifically, OBPR's Physical Sciences Research Division will brief NASA Explorer School (NES) team members on microgravity, how NASA creates reduced-gravity environments on Earth, and why NASA conducts experiments in microgravity.

Two educational tools will allow students to gain some feel for microgravity on Earth. The wireless drop tower consists of a camera inside a box; when the box falls into a catch bucket, the camera captures the action and effect of freefall on various payloads, such as a candle flame. The cardboard glovebox allows students to replicate several experiments in a model of the Microgravity Science Glovebox on the space shuttle's middeck.

A biological OBPR activity is "Plants In Space," in which students grow corn and soy plants in their classroom and compare the plants' physical features to those of the plants grown in space.

serving grades 5–8 and underserved populations (rural and community schools) were encouraged to apply. The educators on the team must have access to the Internet.

NES teams comprise three or four science, math, and technology teachers and include at least one school administrator. Through NES online applications, teams submitted educator profiles, school demographics, information about students' access to computers and other technology tools, and long-term goals for reforming their curricula.

This year, each NASA field center will be responsible for mentoring five schools within its region. The NASA adventure begins with a summer workshop in July. Each NES team will travel to its assigned field center to map out a three-year learning strategy individualized for its school. The team, recognizing its school's needs in science, mathematics, and technology, will target specific areas where NASA's materials could revitalize the curriculum, and will strategize on how to use NASA resources through distance learning and state curriculum consultants. At the workshop, the NES teams also will get to explore hands-on NASA educational materials and figure out how to incorporate them in their own lesson plans. NASA researchers and engineers will be accessible to suggest applications related to science, math, engineering, and technology.

Plug In Your Mind

Teachers are not the only ones getting a chance to tinker with high-tech tools. Students, the primary beneficiaries, will learn to harness the power of technology, sharpen their learning skills, and absorb concepts with inquiry-based activities. For example, the Earth Science Enterprise, through its Earth Observatory Website, gives students the power to collect, view, and analyze near real-time satellite data. Such hands-on activities offer insights into mechanical processes and electronics and NASA-related areas that cannot be gained in any other way. In addition, Internet access can connect students to remote-sensing imagery, NASA websites, interactive exercises, and global communications that can spark imagination and further understanding of math and science concepts.

"We are also hoping that NES students will be involved with gathering actual scientific data in a virtual way or by tele-presence," Steffen says. "We are encouraging them to participate in competitive opportunities that allow them to be involved in experiments flying aboard the ISS. Students can log on to a student-observation network, where data is made available for them to use in their own investigations in the classroom. They will be using technology to connect to scientists and NASA research."

With a few clicks of the mouse, online activities and educational products, fact sheets, and databases focused on human physiology, physical sciences, Earth science, space science, aviation and aeronautics, the space shuttle, and the International Space Station will all be resources for Explorer School students and educators.

Chris McLemore

For more information about the NASA education program, go to *http://education.nasa.gov*.

More OBPR Resources for NES

The Brain in Space: A Teacher's Guide With Activities for Neuroscience. (Grades 5–12). Provides background material and activities related to NASA's Neurolab research. *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/The.Brain.in.Space/*

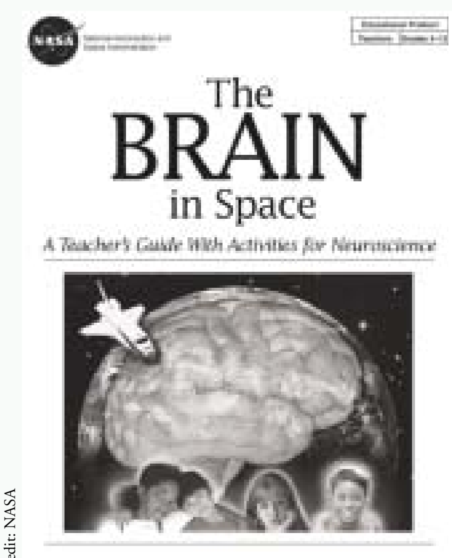
The Mathematics of Microgravity. (Grades 5–12). Explains microgravity and the methods NASA uses to create a microgravity environment. Associated with each text section are activities dealing with computation, measurement, estimation, and algebra. *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Mathematics.of.Microgravity*

Muscles and Bones. (Grades 5–8). Offers teachers 10 activities that help students understand how the body's muscles and bones work and explore important questions related to muscles and bones in living things. *http://www.nsbri.org/Education/MuscleUnit.pdf*

NASA's Student Glovebox: An Inquiry-Based Educator's Guide. (Grades 5–8). Includes instructions for assembling a Student Glovebox, information about its parts and their functions, and a lesson plan for an inquiry-based activity inside the completed glovebox. *http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Support/Physical.Science/Microgravity/NASA.Student.Glovebox/.index.html*

Using Space for a Better Foundation on Earth. (Grades 5–8). Helps students better understand the nature of granular materials. Provides background information about interparticle friction and geometric interlocking between particles. *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Mechanics.of.Granular.Materials/Mechanics.of.Granular.Materials.5-8.pdf*

What's Up With Jose and Cecilia's Story. (Grades 5–12). Features problem-based case studies on sleep, circadian rhythms and neurovestibular function giving students enough information to proceed with their own independent investigations to solve the problem at hand. *http://www.nsbri.org/Education/Jose.pdf* and *http://www.nsbri.org/Education/Cecilia.pdf*



credit: NASA

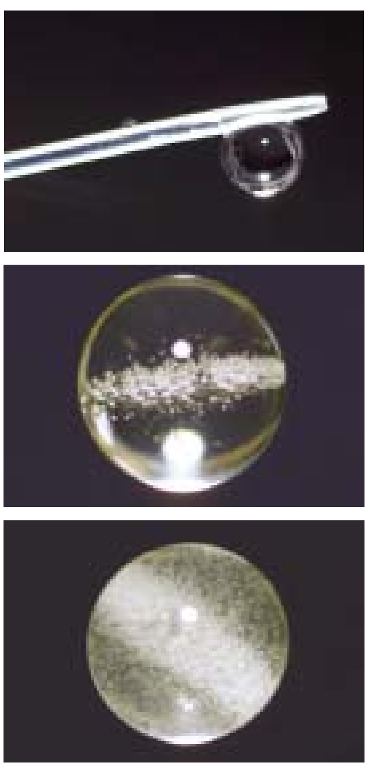
A wide variety of materials, such as "The Brain in Space" teacher's guide, is available to NASA Explorer Schools and other schools that want to enrich their science curricula.

What's Happening on the International Space Station?

Ongoing research being conducted by the Physical Sciences Research and Space Product Development Divisions is highlighted in this installment of "What's Happening."

Although the ISS Expedition Seven crew has been reduced to two members to ease the demand on consumables aboard the ISS, research is still being conducted by the principal investigators (PIs) of the Office of Biological and Physical Research (OBPR). The Physical Sciences Research Division had several new experiments that arrived onboard the ISS along with the Expedition Six crew in November 2002.

One of these experiments, "Coarsening of Solid-Liquid Mixtures-2" (CSLM-2), previously flew on the Microgravity Sciences Laboratory–1 (MSL–1) and the MSL–1 Reflight, both in 1997. When metal alloys have been heated during processing, often one of the alloy's metals cools faster than the other. The faster-cooling metal typically forms solid particles in the mixture larger than the corresponding particles of the slower-cooling metal(s) in the mixture. In the presence of gravity, sedimentation causes the larger particles to fall to the bottom and the lighter particles to remain at the top, resulting in a structurally weak alloy. This process is called coarsening.



credit: NASA

These three images show bubble formation during the Zeolite Crystal Growth (ZCG) experiment on the International Space Station (ISS). Experiment results showed that the bubbles could cause the growth of a larger number of smaller deformed crystals.

On Earth, experiments to quantify coarsening of solid-liquid mixtures can be conducted only with relatively large volume fractions of solid where the presence of a solid skeletal structure prevents large-scale particle sedimentation. Experimentally, solid-liquid mixtures undergo coarsening more rapidly than is predicted by theory for purely diffusion-controlled conditions.

With CSLM-2, PI Peter Voorhees of Northwestern University in Evanston, Illinois, hopes to eliminate sedimentation effects due to gravity to study mixtures with low volume fractions of solid and compare their results with theoretical models of coarsening.

Voorhees's solid-liquid mixtures consist of tin-rich particles in a lead-tin eutectic mixture (a mixture of two or more substances in proportions that give the lowest freezing or melting point) because such systems have a high coarsening rate, which allows accurate kinetic data to be obtained.

CSLM-2 ran from November 2002 until early 2003, when the current experiment returned to Earth. An additional CSLM-2 experiment arrived on station in late spring 2003 and will remain until fall 2003.

PI Alice Gast of Stanford University, Stanford, California, is looking at the fundamental particle motions of dilute magnetorheological suspensions in "Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions," or "InSPACE." In such suspensions, dipolar (having two magnetic poles) particles aggregate into long chains along the lines of an applied magnetic field, causing the fluid to solidify into a paste-like consistency. When the magnetic force is removed, the solution reliquefies. However, those same long chains can also interfere with the ability of the emulsion to stiffen as it should when magnetized.

Gast's experiment will investigate the fundamental particle motions of such systems in an attempt to draw a relationship between changes in the fluid's structure and the interactions of its particles. InSPACE was conducted from November 2002 until early spring 2003.

Protein crystal growth (PCG) experiments, started in spring 2001, are continuing aboard the ISS, using the PCG Single-Locker Thermal Enclosure System (STES). PIs Daniel Carter of New Century Pharmaceuticals, Huntsville, Alabama, and Craig Kundrot of Marshall Spaceflight Center (also in Huntsville), hope to achieve three goals with their research: increased capacity and throughput of the PCG facility, larger protein crystals, and greater understanding of the effect of microgravity on crystal growth and quality.

The PCG experiments that arrived on the ISS in November 2002 will return to Earth in early 2004.

Space Product Development also has an ongoing experiment aboard the ISS, the Zeolite Crystal Growth Furnace (ZCG). (For an in-depth discussion of ZCG research, see *Space Research*, Vol. 1, No. 4, p. 20.)

Zeolite crystals have a three-dimensional structure that enables them to selectively filter certain chemicals, making them commercially useful as catalysts and absorbents. PI Albert Sacco Jr., of the Center for Advanced Microgravity Materials Processing in Boston, Massachusetts, is growing larger and better-formed zeolite crystals in microgravity than can be grown on Earth.

Sacco's research aboard the ISS is obtaining data on how subtle changes in chemical formulation of the zeolites affect nucleation and crystal growth. The study is also validating a new version of the ZCG furnace, which was redesigned to allow growth of ferroelectric (iron-based) and silver halide materials. The ZCG experiment has been running since December 2001 and will continue into 2004.

For information on new and ongoing experiments on the ISS, visit *http://spaceresearch.nasa.gov/research_projects/ros/ros.html*.

RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Research Opportunities in Physical Sciences

NASA Research Announcements (NRAs) for the five discipline sections of the Physical Sciences Research (PSR) Division for fiscal year (FY) 2003 are as follows:

- **Biotechnology:** NRA-02-OBPR-03-A has been cancelled due to programmatic restructuring. For more information, see *http://spaceresearch.nasa.gov/news/news.html#228*.
- **Combustion Science:** NRA-02-OBPR-03-B selections are expected by September 2003.
- **Fluid Physics:** NRA-02-OBPR-03-C opens September 10, 2003, with proposals due December 10, 2003.
- **Fundamental Physics:** NRA-02-OBPR-03-D selections will be made in October 2003.
- **Materials Science:** NRA-02-OBPR-03-E opened June 30, 2003, with proposals due September 30, 2003.

Further information on these announcements can be found on the World Wide Web (WWW) at *http://research.hq.nasa.gov/code_u/open.cfm*.

In addition, selections are still being made for NRA-01-OBPR-08, the PSR Division's NRA for 2002. The discipline sections with selection dates in 2003 are as follows:

- **Biotechnology:** NRA-01-OBPR-08-B proposals were due September 3, 2002, and selections are expected in the summer of 2003.
- **Special Focus Theme, Materials Science for Advanced Space Propulsion:** NRA-01-OBPR-08-G proposals were due September 3, 2002. Selections were made in the spring and awards will be presented later in 2003.

For more information on these announcements, see *http://research.hq.nasa.gov/code_u/nra/current/NRA-01-OBPR-08/index.html*.

Research Selections Made for Fluid Physics

NASA has selected 30 researchers to receive grants totaling more than $13 million over four years to conduct ground-based research in fluid physics. By December 2001, 197 proposals had been received in response to NRA-01-OBPR-08-D, one in a suite of NRAs released in FY 2002 that covered all of the Physical Sciences Research Division disciplines. A list of awardees can be found at *http://spaceresearch.nasa.gov/general_info/OBPR-03-185.html.*

Solicitation for Advanced Human Support Technology Program

The Advanced Human Support Technology program is soliciting research proposals through NRA-03-OBPR-01. Research will develop new technology to help minimize some of the relevant risks identified in the OBPR Critical Path Roadmap. Proposals were due June 13, 2003, with selections to be made in November 2003. For additional information, see *http://research.hq.nasa.gov/code_u/nra/current/NRA-03-OBPR-01/NRA-03-OBPR-01.pdf.*

Research Opportunities in Space Radiation Biology

NRA-03-OBPR-02 solicits research proposals for NASA Specialized Centers of Research in support of Space Radiation Research in the Bioastronautics Research and Fundamental Space Biology Divisions. Proposals were due June 2, 2003, with selections to be made in August 2003. For more information, see *http://research.hq. nasa.gov/code_u/nra/current/NRA-03-OBPR-02/NRA-03-OBPR-02.pdf.*

Research Opportunities in Biomedical Research and Countermeasures Program

OBPR released NRA-3-OBPR-04 to solicit ground-based research proposals for the Biomedical Research and Countermeasures Program (BR&C). The BR&C Program sponsors research for the development of countermeasures against the negative effects of spaceflight on humans. This NRA does not solicit research into countermeasures against radiation. Proposals were due July 15, 2003. For additional information, please see *http://research.hq.nasa.gov/code_u/nra/current/NRA-03-OBPR-04/index.html.*

Solicitation for Fundamental Space Biology Ground-Based Research

Proposals for research in Space Life Sciences are being solicited through NRA-03-OBPR-03 for the Fundamental Space Biology Division. Selected research will increase fundamental knowledge of biological processes, support exploration, and enrich life on Earth. Proposals were due on July 15, 2003. For more information, please see *http://research.hq.nasa.gov/code_u/nra/current/NRA-03-OBPR-03/index.html.*

TECHNICAL MEETINGS

Microgravity Transport Processes in Fluid, Thermal, Biological, and Materials Sciences Conference III

Davos, Switzerland
September 14–19, 2003
http://www.engconfintl.org/3au.html

This year's international conference will provide an opportunity for researchers from the various transport fields to gather and exchange ideas and information. Organized by the United Engineering Foundation, attendees will include researchers from universities, government laboratories, and private industries. General topics of papers and presentations will include boiling phenomena, bio-transport processes, acoustic levitation studies, and materials processing, all as related to microgravity. Activities will also include a "show and tell" session where speakers can bring in and demonstrate experiment apparatus.

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For example, once a molecule has been tagged for fluorescence (as in Venkat's ATP assay using the firefly enzyme), Hines explains, "all I need is a detector to see the light — a mature technology. But *how* do I get a sample to emit light specific only to the one analyte I am looking for? *How* do I filter, heat, add reagents [substances used to detect or measure an analyte], separate, and tag the sample according to well-accepted protocols before it can even be presented to the sensor? *How* do I design the reservoirs of reagents, valves, and pumps for each stage in the process? And *how* can all those intricate functions — usually done by trained personnel in a major laboratory — be done automatically in the volume of a shoebox?"

In the context of bioterrorism, data acquisition and dissemination are also essential. Autonomous sensors that continuously monitor air and water from office building air intakes or reservoir water intakes must be equipped with wireless devices for communicating their readings in real time to a local data-collection point. Moreover, data acquisition and dissemination are vital to first responders in an actual terrorist attack because "their protective gear has to be completely self-contained," Hines points out. Sensors embedded in protective suits could ascertain whether or not they have been exposed — even helping responders decide whether they have to wear bulky protective gear at all. If they have been exposed, sensors with real-time communications to databases could even determine "to what they have been exposed, and to what degree," Hines continues.

NASA's Liaisons for Homeland Security

In August 2002, NASA appointed Amy Donahue, assistant professor in the graduate program of public administration at the University of Connecticut, Storrs, as senior adviser to the NASA Administrator for homeland security. Donahue, loaned to NASA for at least a year through the Intergovernmental Personnel Act, is a former firefighter whose academic interests center on emergency and crisis management. She is serving as NASA's liaison to the Department of Homeland Security (DHS); she is also advising NASA Administrator Sean O'Keefe on how NASA might protect its own launch pads and other physical assets as well as organize, coordinate, and institutionalize any dual-use research, being space-related and with possible applications to homeland security.

Donahue's right hand is Kathryn "Kitty" Havens, manager of homeland security and intelligence community liaison, in the technology and assessments office at NASA Headquarters. In late 2002, Havens solicited NASA's five major enterprises to seek out possible dual-use research projects. By March 2003, her staff had amassed one-page descriptions of more than 275 projects, and had coordinated the formation of a team "to examine and prioritize the projects or technologies potentially most beneficial both to NASA and the DHS," Havens says.

In the summer of 2003, the two liaisons hope to host a meeting to introduce DHS representatives to NASA's wealth of expertise in information technology, "including cybersecurity, data fusion, and management and interoperability of large data sets. "The best ideas we have are those that come from within. As the DHS learns about various dual-use research at NASA, I think we will become more and more important to homeland security," Havens says.

Meeting the Challenges

The technical challenges of preventing, detecting, and combating bioterrorism are great. But the technical challenges of keeping astronauts healthy in space for months at a time are also great — and the similarity of the challenges means NASA has much to contribute to protecting our home planet.

"Although NASA is not in the business of fighting terrorism on Earth, NASA is in the business of keeping astronauts safe," Joshi states. "But whatever works for astronauts can improve life on Earth. And if we are successful, that can translate very well to meeting today's challenges."

Trudy E. Bell

NASA's 2003 Strategic Plan, which details NASA's Mission I, "To Understand and Protect Our Home Planet," as well as NASA's responsibility to help contribute to homeland defense, can be downloaded from *http://ifmp.nasa.gov/codeb/docs/2003_Strategic_Plan.pdf*.

Fact sheets about diseases and agents likely to be used in bioterrorism are available from the Centers for Disease Control at *http://www.bt.cdc.gov*.

James Lambert's test strips for identifying pathogens in water are so new his results have not yet been published, but a brief description of his work can be found at *http://research.hq.nasa.gov/taskbook/tb2001/search/retrieve_task.cfm?task_id=679*.

Marc Porter's work in monitoring biocide concentration in spacecraft water is described in Arena, M., Porter M., Fritz, J., Mudgett, P., Ruta, J., & Schultz, J. (2002) A Rapid Method for Determining Biocide Concentration in a Spacecraft Water Supply. Technical Paper 2002-01-2535, International Conference on Environmental Systems, San Antonio, TX, July 17–18, 2002. See also *http://research.hq.nasa.gov/taskbook/tb2001/search/retrieve_task.cfm?task_id=205*.

More about ProVision Technology's hyperspectral imaging technique appears in Downsized Technology Reveals Secrets From Slices of Light. June 2002. *Space Research*, 1 (3), 18–19, 25.

Details about Kasthuri Venkateswaran's ATP assay has been published in Venkateswaran, Kasthuri, Noriaki Hattori, Myron T. La Duc, & Roger Kern (2003). ATP as a Biomarker of Viable Microorganisms in Clean-Room Facilities. *Journal of Microbiological Methods* 52, 367–377.

Information about Weijia Zhou's titanium dioxide ethylene scrubber can be found at *http://wcsar.engr.wisc.edu/ethylene.html*. How it led to John Hayman's AiroCide TiO_2 for killing airborne *Bacillus anthracis* spores can be found at *http://www1.msfc.nasa.gov/NEWSROOM/news/releases/2002/02-056.html*. See also the Science@NASA article "Annihilating Anthrax" at *http://science.nasa.gov/headlines/y2002/01feb_anthrax.htm*.

Plasmas *continued from page 13*

Earthly Uses

Many of the decontamination techniques under development for NASA have direct application on Earth. Sterilizing a Mars probe, for example, is not all that different than sterilizing the surfaces of medical instruments. Korfiatis envisions plasma systems for military medical use.

"Doctors in hospitals work in a sterile environment, but military doctors in the field do not have that," he notes. "The only point of transmitting an infection is the opening in the body. Our concept is to sterilize the area around the wound with a plasma. Any instrument you pass through the field automatically would be sterilized."

An even more significant use lies in indoor air decontamination. Many homes and commercial buildings now filter air, but even electrostatic and high-efficiency particulate air (HEPA) filters are not 100% efficient. In fact, often they become breeding grounds for microbes. A hybrid plasma/filter system, however, would kill most bacteria and spores and filter out the rest. The system could be used in homes and offices, and also in hospitals to suppress the spread of airborne disease from one patient to another.

The same technology could also protect stadiums, malls, office buildings, and other large structures against bioterrorism. Most experts believe terrorists would try to disperse weapon-grade bacteria or spores as aerosols through ventilation systems. Placing a plasma/filter system near a building's air intake system could protect against such an attack.

Plasma/filter systems are already being marketed through a company, PlasmaSol Corp., started by Korfiatis, Kunhardt, and Becker at the Stevens Institute of Technology business incubator in Hoboken. PlasmaSol also develops cold plasma products for NASA and industry.

There are still technical issues to resolve. For example, although the researchers have several theories, they do not fully understand why capillary discharge works. Their equipment configurations continue to change. They have not yet optimized their ability to treat pollutants without creating NOx. Yet PlasmaSol sees potential applications everywhere. Plasmas may one day break down pollutants from coal-fired power plants, making the United States' most plentiful fuel more environmentally acceptable. They may destroy VOCs generated in factories and refineries. They may treat underground pollutants and remove surface oils and contaminants from metals and plastics during manufacturing.

The possibilities seem virtually endless — which suggests that today's slightly exotic fourth state of matter may indeed matter more in the future.

Alan S. Brown

For more information on Korfiatis' research, visit *http://research.hq.nasa.gov/taskbook/tb2001/search/retrieve_task.cfm?task_id=104*.

Macrophage *continued from page 15*

sitting on the cell surface ready to bind CSF-1 — then macrophage differentiation could be inhibited. If c-*fms* is normal, then Chapes will examine pathways inside the cell to look for a defect in the way CSF-1 binding transmits signals to the cell's nucleus. Chapes will also look for markers on the cell's outer membranes that distinguish differentiated macrophages from still-immature cells.

Once the defect is pinpointed, he says, effective therapy can be designed. Designing an effective way to help bone marrow macrophages differentiate in microgravity would depend on where the defect is occurring, says Chapes. If, for example, c-*fms* receptors were not being made, then a drug would have to be found that could regulate c-*fms* expression. If the cell makes enough receptors to bind CSF-1, then a drug would have to be targeted toward one of the signaling pathways inside the cell.

It is most important, says Chapes, to know the basic biology of the cell. Without that understanding, any defect in the macrophage biology of astronauts or people on Earth cannot be addressed. Work that furthers that knowledge holds the promise of therapies that may help immune systems that are not functioning as they should and may also improve the skeletal health of people in what are called unloaded environments, such as spaceflight, long-term bed rest, or confinement to a wheelchair.

Universal Answers

For Chapes, the work goes beyond the practical to a more fundamental understanding of how life on Earth evolved. We all search for answers, he says, sometimes for purely intellectual reasons. Whether you look at cells through a microscope, at heavenly bodies through a telescope, or peer back at Earth through the window of an orbiting spacecraft, we want to know why. Chapes is ultimately seeking how changes in gravity affect cells. "It is important for people to understand that every biological process that goes on in animals or humans has evolved in the presence of gravity," he remarks. "Gravity is such a pervasive force. Very few people think about the fact that all of the cell functions that go on in a whole organism have evolved in the presence of this pervasive force. Now you take it away and it is not automatic that everything is going to function the same way."

Jeanne Erdmann

To learn more about the effects of microgravity and spaceflight on macrophages visit *http://spacebio.net/modules/ih_resource/macrophages/index.htm* or read Chapes, S. K., D. R. Morrison, J. A. Guikema, M. L. Lewis & B. S. Spooner. (1992). Cytokine secretion by immune cells in space. *Journal of Leukocyte Biology. 52*: 104–110; Armstrong, J. W., R. A. Gerren & S. K. Chapes. (1995). The effect of space and parabolic flight on macrophage hematopoiesis and function. *Experimental Cell Research. 216*: 160–168.

Lowering Lignin *continued from page 19*

NASA and commercial interests in three areas: life support (such as spinach and tomatoes for food), medicine (Madagascar periwinkle, a source of alkaloids), and structural support (loblolly pine). The flights demonstrated that these plants could be grown effectively in space.

In the most recent experiments, aboard the International Space Station (ISS) during Expedition 5 in 2002, the Commercial Generic Bioprocessing Apparatus (CGBA) unit was added to the experiment for the first time. The CGBA, the final piece of the hardware suite that is essential to conducting this type of research, preserves the plant material grown in space so that it can be studied back on Earth. “Growing high-quality materials in space is only half the story,” Heyenga says. “The other half is being able to preserve it without any changes to the plant material so it can be returned to Earth for analysis.” During Expedition 5, *Arabidopsis thaliana*, a member of the mustard family, grew in the hardware as a stand-in for the pines while new hardware was being completed. Heyenga summarizes, “This flight allowed us to set up final protocols for conducting the experiment on the ISS, which we are now prepared to do.”

Growing Trees With Reduced Lignin Levels

The next space mission for growing loblolly pine (*Pinus taeda*) will include a 3- to 4-month growth period in the PGBA aboard the ISS with the astronauts’ harvesting and preserving seedling specimens at selected intervals for detailed analysis back on Earth. Harvesting the pines in orbit is crucial since even a few hours’ wait after landing is several times longer than the time it takes an organism’s chemistry to start adapting to Earth’s gravity. (While industrial factories may seem slow and ponderous, a cell’s molecular factory fills its quotas in fractions of a second and then moves on to the next order.)

Beyond space experiments lies a long, demanding process to identify the genes that trigger down-regulation of lignin in microgravity. Then researchers will need to determine whether those genes can be manipulated on Earth to effect a permanent alteration that can be propagated from one generation to the next, and thus develop a line of trees to grow on Earth with reduced, controllable levels of lignin.

Heyenga does not envision producing lignin-free trees. A tree with the strength of seaweed (which has no structural lignin) will not grow to be harvested. “But a 10- to 15-percent reduction in lignin content would provide dramatic financial and environment benefit, while incurring little loss to the physical stature of the tree, particularly if grown in a crop environment,” where trees do not compete with each other and could be surrounded by a perimeter of stronger trees as a barrier between the crop and strong winds and other natural threats, he says.

It may take 30 years or more before the first controlled-lignin trees reach pulp mills because of the time it takes to identify the genes and then to grow the trees. In turn, that is a challenge for business partners riding the inevitable ups and downs of the economy. But it could be worth the wait.

“The advantage for the pulp industry, just in energy costs, could be billions of dollars a year,” Heyenga predicts.

Another industry that could see benefits is the pharmaceutical industry. “Lignin is like a six-lane motorway,” Heyenga says. “It is a major [energy] sink in the plant’s metabolic pathway,” the chemical processes of life. “Blocking one or two lanes would force a plant to divert that metabolic energy [away from producing lignin]. The diversion could result in increased production of vitamins and pharmaceutically valuable compounds, such as lignans and neo-lignans (closely related to lignin), many of which have useful medicinal and anti-cancer properties.”

Dave Dooling

For more information on Heyenga’s research on lignin, go to *http://www1.msfc.nasa.gov/NEWSROOM/background/facts/PGBA_Bioserve.html* on the World Wide Web.

Meetings *continued from page 23*

EDUCATION

2003 National Association of Biology Teachers National Convention

Portland, Oregon
October 8–11, 2003
http://www.nabt.org/sup/conferences/2003conv.asp

This year’s convention will gather biology educators from across the country to compare and share the latest in teaching methods and technology. Speakers include Nina Jablonski of the California Academy of Science, San Francisco; Sue Dale Tunnicliffe, University of London, London, England; William McComas, University of Southern California, Los Angeles; and Barry Lynn, Americans United for the Separation of Church and State, Washington, D.C. In addition to the regular program, this year’s convention is also offering several short courses on such topics as making low-cost biotechnology kits for classroom experiments, recent advances in proteomics and nanotechnology, and a joint study of plants and butterflies.

PROGRAM RESOURCES

Office of Biological and Physical Research
http://spaceresearch.nasa.gov
• Latest biological and physical research news
• Research on the International Space Station
• Articles on research activities
• Space commercialization
• Educational resources

Descriptions of Funded Research Projects
Science Program Projects
http://research.hq.nasa.gov/taskbook.cfm
Commercial Projects
(also includes links to a description of the Commercial Space Center Program and other information)
http://spd.nasa.gov/sourcebook/index.html
Space Life Sciences Research Resources
(for literature searches)
http://spaceline.usuhs.mil/home/newsearch.html

Profile: Khalid Alshibli

Commitment — and excitement — are integral to Khalid Alshibli's work as project scientist for the Mechanics of Granular Materials experiment and professor at Louisiana State University and Southern University.

Excitement born of commitment can be infectious. When project scientist for the Mechanics of Granular Materials (MGM) experiment, Khalid Alshibli, invites undergraduate students to work with him, his enthusiasm rubs off. "I have many of them come to work with me for just one day. At first, they say, 'Well, I'm just trying to finish my undergraduate degree and go and find a job.' But once students know more about all we are doing and that we are conducting experiments on the space shuttle, they really become very excited," Alshibli recounts. "They work with me for one or two semesters, and then most of them stay with us for a graduate degree."

A professor of geotechnical engineering (civil engineering applied to soil and building foundations) at Louisiana State University and Southern University, both in Baton Rouge, Alshibli has been working with MGM for 10 years now. He started as a doctoral research assistant at the University of Colorado, Boulder, under MGM Principal Investigator (PI) Stein Sture. Alshibli was fascinated by the research because "Soil liquefaction has been haunting us here on Earth," he explains. "Every time an earthquake hits an area with sand deposits under a groundwater table such as the west coast of the United States, the sand liquefies [behaves like quicksand]. Once the sand liquefies, you have sinkholes and boiling sand, which result in devastating damage for all structures in these areas."

As a doctoral student, Alshibli wanted to understand what happens when soil liquefies, and Sture was headed for low Earth orbit to find answers. "In the lab," Alshibli says, "we can make the soil liquefy, but gravity collapses the soil in maybe 2, 3 seconds" — not enough time to measure the soil properties. In orbit, the effects of gravity are minimized "so we could study liquefaction and get good measurements."

After earning his doctorate, Alshibli wanted to continue working with MGM. "I moved to Huntsville, Alabama, in 1995 to establish a testing lab for our experiment at Marshall [Space Flight Center]," he recalls. From 1995 to 1998, he worked as a research associate for the PI as well as for the project scientist at that time, Marshall employee Nicholas Costes. When Costes retired in August 1998, Alshibli himself became project scientist. Alshibli says of the change, "I'm doing more supervising right now rather than doing the [scientific] trench work."

Under Alshibli's supervision, MGM flew on Space Shuttle *Columbia* for mission STS-107 in January 2003. The crew, as well as most of the experiments onboard the science-dedicated flight, perished on February 1, 2003, when the space shuttle broke apart during its reentry into Earth's atmosphere.

For the week and a half before the tragedy, however, Payload Commander Michael Anderson, Mission Specialist Kalpana Chawla, and other crew members conducted dozens of biological and physical sciences investigations. For the MGM experiment, Anderson and Chawla used a new procedure developed by the MGM project team to reform (recycle) soil specimens. The experiment involved compressing a cylinder of wet sand while maintaining control of water pressure inside and around the sand specimen. "In the past on every mission we flew three test cells, and once we compressed a specimen, that was it — we could not get more science out of it," Alshibli explains. "In the STS-107 mission, we employed a new technique, so after we tested the specimen and compressed it, we could reform it and conduct more experiments."

Working with Anderson and Chawla was the MGM project team on the ground, using new flight hardware that could be controlled from Earth. "We had a live uplink," says Alshibli, so the experiment required only minimal time from the space shuttle crew, compared to older hardware used for STS-79 in 1996 and for STS-89 in 1998. "In flight, we were able to trigger or reproduce liquefaction,


credit: NASA

and the liquefied sand specimen did not collapse in space. We were very successful."

The ground team also had a live downlink of data and results. "We acquired data once every 10 seconds from nine out of 10 experiments, about 40–50 percent of all the MGM data recorded onboard," explains Alshibli. Data cards onboard the space shuttle downloaded all data once a second, but the cards were lost in the accident. "Now we are filtering the data of any anomalies caused by signal interference during data transmission from *Columbia* to Johnson Space Center, and then analyzing the filtered data."

Alshibli attributes the fact that there are any data to analyze at all largely to the *Columbia* crew. "Mike [Anderson] and KC [Kalpana Chawla] were part of a very special crew. On day 10, they were off duty, but they decided to work anyway to catch up on some of the science that had been missed. They were very dedicated."

So is Alshibli. New developments such as the telemetry-controlled hardware and the hope of applying future MGM findings toward safer building designs keep him committed to the research and the work for which the crew of the *Columbia* made such a great sacrifice. "The seven crew members are irreplaceable," he reflects. "We had some minor setbacks in losing MGM experiment data, but the loss of the crew will affect the rest of my life."

He adds, "There is risk in everything we do in life. The *Columbia* tragedy should not cause us to retreat — I hope that we will soon be ready to explore again and push the envelope of knowledge further."

Julie Moberly

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